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Joint Norwegian-Russian environmental status 2013 Report on the Barents Sea Ecosystem Part II - Complete report

Editors:
M.M. McBride, J.R. Hansen, O. Korneev, O. Titov

Co-editors
J.E. Stiansen, J. Tchernova, A. Filin, A. Ovsyannikov

Institute of Marine Research - IMR

Polar Research Institute of Marine Fisheries and Oceanography - PINRO

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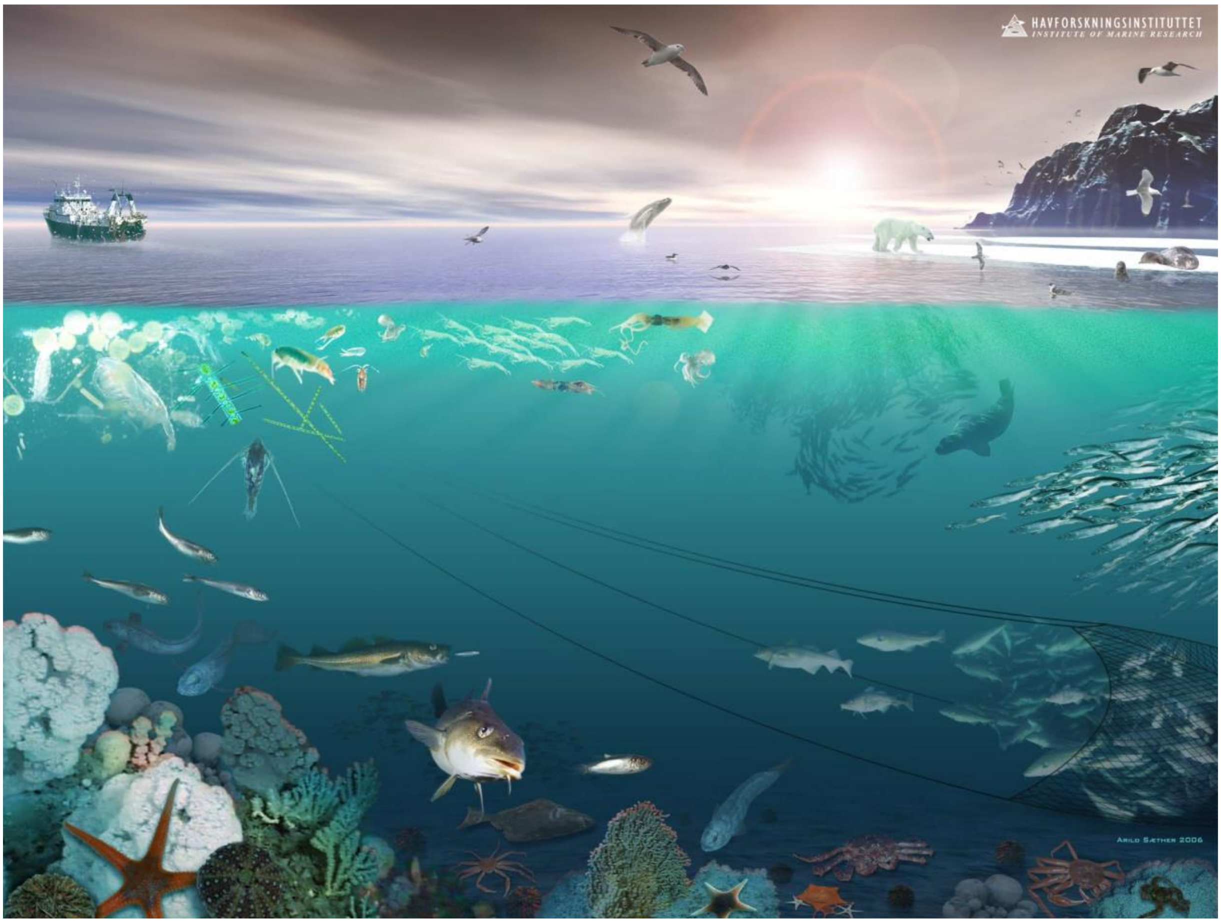


Illustration of the rich marine life and interactions in the Barents Sea

Bergen, May 2016

Contributing authors in alphabetical order:

S. Aanes[1], J. Aars[4], G. Alekseev[6], J. Anders[1], N. Anisimova[3], P. Arneberg[4], B. Baik[16], S. Bakanev[3], A. Bambulyak[10], S.E. Belikov[11], I. Berchenko[7], B. Berenboim[3], I. Berthinussen[19], O.K. Bjerkemo[20], B. Bogstad[1], S. Denisenko[27], S. Denisenko[27], S. Descamps[4], A.V. Dolgov[3], K. Drevetnyak[3], K. Drinkwater[1], E. Druzhkova[7], A. Dvoretsky[7], S.F. Eggereide[16], K. Enberg[28], E. Eriksen[1],S. Falk-Petersen[4], P. Fauchald[12], A. Filin[3], B. Frantzen[31], A.K. Frie[1], G. Gabrielsen[4], K.L. Gabrielsen[9], M.V. Gavrilo[6], H. Gjøsæter[1], H. Goodwin[4], E.H. Hallfredsson[1], K. Handeland[14], T. Haug[1], D. Howell[1], C. Hvingel[1], Å. Høines[1], G.V. Ilyin[7], R. Ingvaldsen[1], P.E. Iversen[19], A. Jelmert[1], E. Johannesen[1], T. Johnsen[8], C. Jørgensen[28], L.L. Jørgensen[1], N.M. Jørgensen[10], O. Kalinka[7], R. Kallenborn[25], O. Karamushko[7], A. Karasev[3], A.L. Karsakov[3], N. Kasatkina[7], M.R. Kleiven[1], R. Klepikovsky[3], R. Kluge[19], J. Klungsøyr[1], T. Knutsen[1], T. Knutsen[1],J.H. Koefoed[26], A.G. Kolstad[19], O. Korneev[2], K.M. Kovacs[4], Y.A. Kovalev[3], J.V. Krasnov[7], V. Kuklin[7], C. Kvamme[1], J.A. Kålås[15], V. Larionov[7], L.H. Larsen[10], S.H. Larsen[1], V. Lien[1], O.W. Lind[18], N.N. Lukin[3], S. Lunde[20], C. Lydersen[4], P. Lyubin[3], O. Lyubina7, A. Maage[33], P.R. Makarevich[7], I. Manushyn[3], M.M. McBride[1], S. Mehl[1], K. Michalsen[1], D. Moiseev[7], A. Nalbandyan[23], L.J. Naustvoll[1], K. Nedreaas[1], V. Nesterova[3], P.B. Nizzetto[25], T. E. Nordeng[5], M. Novikov[3], E. Olsen[1], C.D. Olseng[19], E. Orlova[3], A. Ovsyannikov[2], V.K. Ozhigin3, A. Pavlenko[3], V. Pavlov[3], G. Pedersen[10], C.F. Pettersen[19], M. Pinchukov[3], N.F. Plotitsyna[3], I. Prokopchuk[3], D.V. Prozorkevich[3], O. Raustein[18], M. Reigstad[9], P. Renaud[10], G.B. Rudneva[3], A.A. Russkikh[3], A.E. Rybalko[2], I. Røttingen[1], R. Sabirov[29], I. Salvesen[15], E. Shamray[4], A. Shavykin[7], M.S. Shevelev[3], T. Shirokolobova[7], N. Shtikova[2], G. Skaret[1], M. Skern-Mauritzen[1], M. Skogen[1], O.V. Smirnov[3], K. Sokolov[3], J.E. Stiansen[1], R. Storebø[18], A.B. Storeng[17], H. Strøm[4], J. Sundet[1], O. Svetocheva[7], V.N. Svetochev[7], G.H. Systad[12], E.E. Syvertsen[19], A.L. Sørensen[17], T. Sørgård[19], G. Tertitski[32], T. Thangstad[1], O.V. Titov[3], S. Tjelmeland[1], A.G. Trofimov[3], M. Tryland[9], M. Tsyganova[11], H. Wolkers[4], G. Van der Meeren[1], B. Vanstein[24], R. Vogsholm[20], D. Vongraven[4], A. Yurko[3], O. Yurko[3], V. Zabavnikov[3], D. Zacharov[3], A. Zhilin[3], S. Ziryanov[3], P. Zolotarev[3], P. Zolotariov[3], N. Øien[1]

[1] Institute of Marine Research (IMR), Norway	[17] Directorate for Nature Management (DN), Norway
[2] SEVMORGEO (SMG), Russia	[18] Norwegian Petroleum Directorate (OD/NPD), Norway
[3] Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Russia	[19] Norwegian Environmental Agency (NEA), Norway
[4] Norwegian Polar Institute (NPI), Norway	[20] Norwegian Coastal Administration (KV), Norway
[5] Norwegian Meteorological Institute (MI), Norway	[21] Norwegian Institute for Agricultural and Environmental Research (Bioforsk), Norway
[6] Arctic and Antarctic Research Institute (AARI), Russia	[23] Norwegian Radiation Protection Authority (SSV/NRPA), Norway
[7] Murmansk Marine Institute of Biology (MMBI), Russia	[24] Shirshov Institute of Oceanology (VNIIOceanology), Russia
[8] Norwegian Institute for Water Research (NIVA), Norway	[25] Norwegian Institute for Air Research (NILU), Norway
[9] UiT - Arctic University of Norway	[26] Norwegian Maritime Directorate (NMD), Norway
[10]Akvaplan-niva, Norway	[27] Zoological Institute (ZIN), Russia
[11] All-Russia Institute for Nature Protection (VNIIPriroda), Russia	[28] University of Bergen (UiB), Norway
[12] Norwegian Institute for Nature Research (NINA), Norway	[29] Kazan State University (KSU), Russia
[14] National Veterinary Institute (VI), Norway	[31]Bioforsk Soil and Environment Svanhovd, Norway
[15] Norwegian Biodiversity Information Center (ADB), Norway	[32] Institute of Geography (RAS), Russia
[16] Directorate of Fisheries (FDir), Norway	[33] National Institute of Nutrition and Seafood Research

Table of Contents

1 Introduction

This is the full version of the Joint Norwegian-Russian environmental status 2013 report on the Barents Sea Ecosystem. The report was initiated by the Joint Russian-Norwegian Commission on Environmental Cooperation and the work has been carried out in co-operation with the Joint Russian-Norwegian Fisheries Commission.

The main objective of this report is to provide a comprehensive description of the Barents Sea ecosystem using relevant scientific knowledge from both Russian and Norwegian scientists. The report is aimed at groups such as decision makers, professionals involved in ecosystem-based research and management, and journalists. It presents the main findings of expert groups addressing the current status of the Barents Sea ecosystem, including: climate; microbes and viruses; phytoplankton; zooplankton; benthos, shellfish, and squid; fish; marine mammals; sea birds; infectious organisms; threatened and introduced species; fisheries; oil and gas extraction; and pollution.

This report contributes to the scientific basis for further development of a coordinated ecosystem-based approach to the management of human activities affecting living resources in both Norwegian and Russian Territories of the Barents Region. Norway has already developed and implemented an "Integrated management plan for the Barents Sea–Lofoten area"; Russia is working to develop a similar plan.

Development and implementation of ecosystem-based management plans requires extensive information about various components of the system and its dynamic interactions, as well as information about the effects of anthropogenic activities on the ecosystem. Toward meeting these objectives, this report provides a basic description of major components of the Barents Sea ecosystem and how they interact, including the physical environment. It also describes human activities, and discusses their impact on the ecosystem. The status of major ecosystem components is described using the most recent data. Some aspects of long-term change are discussed. In addition, examples of important issues relevant to the development of ecosystem-based management are highlighted.

It should be noted that although core issues are discussed, no attempt is made to address a complete list of relevant themes. Human activities and subsequent anthropogenic impacts are expected to increase in the future. Accordingly, the report emphasizes the importance of monitoring all components of the ecosystem, including human activities, to provide information needed for an integrated ecosystem-based approach to resource management.

This report builds upon earlier reports on the status of the Barents Sea ecosystem developed jointly by the Polar Research Institute of Marine Fisheries and Oceanography (PINRO in Russia) and the Institute of Marine Research (IMR in Norway). This effort has been led by PINRO and SEVMORGEO (SMG) on the Russian side and by the Norwegian Polar Institute and the Institute of Marine Research on the Norwegian side. The expert groups began their work in March 2014; therefore, the report builds on data collected in 2013 and earlier.

2 General background description of the ecosystem

M.M. McBride (IMR), P. Fauchald (NINA), A. Filin (PINRO), Å. Høines (IMR), E. Johannesen (IMR), O. Korneev (SMG), P. Makarevich (MMBI), M. Skern-Mauritzen (IMR), J.E. Stiansen (IMR), and A.B. Storeng (MD)

2.1 Overview of the ecosystem

The Barents Sea is a high-latitude large marine ecosystem that is bordered by Norway and Russia. It is influenced by Atlantic Water to the south and west and by Arctic or mixed (Atlantic and Arctic) water to the north and east. It is the largest and deepest of the Continental Shelf seas surrounding the Arctic Ocean. This region is characterized by: extreme environmental conditions; large seasonal and annual changes in ocean climate; and moderately high productivity. It is a transition zone for warm and saline water on its way from the Atlantic to the Arctic Ocean, and for cold and les saline water on route from the Arctic to the Atlantic (Figure 2.1.1). The Sea is an important feeding area for cod, capelin, haddock, herring, sea perch, catfish, plaice, halibut, Atlantic salmon, and redfish. The system is driven by climate conditions and is highly susceptible to the effects of climate change, e.g., temperature, which strongly influences the distribution, growth, and recruitment of species which support major international fisheries. Nutrient concentrations (nitrates, phosphates, and silicic acid) are significantly lower than in other polar areas (Sakshaug and Holm-Hansen, 1984). The main sources of pollution are: industrial activities linked to marine transport and the extraction of petroleum products (oil and gas); and fresh-water runoff.

Figure 2.1.1. The Barents Sea is a marginal sea of the Arctic Ocean located off the northern coasts of Norway and Russia with vast majority of its area lying in Russian territorial waters.

2.2 Geographic description

The Barents Sea is one of the shelf seas situated on the continental shelf surrounding the Arctic Ocean. It is positioned between 70° and 80°N on the North European continental shelf. Its topographic features include the Svalbard archipelago to the Northwest, and Novaya Zemlya archipelago to the east. It connects with the Norwegian Sea to the west, the Arctic Ocean to the north, and the Kara Sea to the east. Its contours are delineated by the continental slope between Norway and Spitsbergen to the west, the top of the continental slope towards the Arctic Ocean to the north, Novaya Zemlya archipelago to the east, and the coasts of both Norway and Russia to the south (Figure 2.1.1). It covers an area of approximately 1.4 million km^2. It is a relatively shallow sea with an average depth of 230 meters (m) and a maximum depth of about 500m at the western entrance. Its bottom topography (bathymetry) is characterized by troughs and basins (300m – 500m deep) separated by shallow bank areas, with depths ranging from 100-200m. The three largest banks are Central Bank, Great Bank and Spitsbergen Bank. Several troughs over 300 m deep run from central Barents Sea to the northern (e.g., Franz Victoria Trough) and western (e.g., Bear Island Trough) continental shelf break. These western troughs allow the influx of Atlantic Water to the central Barents Sea.

2.3 Abiotic components

A. Filin (PINRO), R. Ingvaldsen (IMR), A.L. Karsakov (PINRO), O.V. Titov (PINRO), A.G. Trofimov (PINRO), and J.E. Stiansen (IMR)

2.3.1 Meteorological conditions

2.3.1.1 Air pressure, winds, and air temperature

Climate conditions in the Barents Sea are determined by both Atlantic and Arctic climate systems. The winter North Atlantic Oscillation (NAO) explains about 15-20% of the inter-annual variability in air and sea temperatures in the southern region. The climate oscillates between warm and cold states. The warm state is characterized by low air pressure over the Sea giving southwesterly winds which cause increased Atlantic inflow, higher seasonal temperatures, and more northward positioning of the Polar Front. Consequently, there is less ice, and heat flux from the sea surface to the atmosphere is high. A high heat flux causes low air pressure and the cycle is closed. The cold state is characterized by a high-pressure center blocking the Atlantic inflow, low sea temperatures and more ice. Low heat flux from ocean to atmosphere thereby creates a high atmospheric pressure. It is uncertain whether the atmosphere is driving the ocean or the ocean driving the atmosphere. In either case, local positive feedback mechanisms are required to strengthen and maintain the existing state, whether warm or cold. Exposed only to local forces, marine climate can be stable; inducing a flip-flop between warm and cold states requires external forcing by large-scale oceanic and atmospheric circulation. In the Barents Sea, a positive NAO index is associated with several processes controlling inflow; a high NAO is associated with both a higher volume flux and higher temperatures of the inflowing water (Ingvaldsen and Loeng, 2009). Spatial and temporal variability of air temperatures in the Barents Sea depends greatly on solar radiation, atmospheric circulation, and transport of warm or cold waters by sea currents. During

January, air temperatures range from -7ºC in the south to -25ºC in the north; during July, temperatures range from 12ºC in the south to 1ºC in the north. There is substantial inter-annual variability of air temperature, but clear similarities occur in year-to-year fluctuations, at least in the southern region (Ozhigin et al., 2011).

2.3.2 Oceanographic conditions

2.3.2.1 Currents and transport / Circulation and inflow

In the Barents Sea, the general pattern of circulation is strongly influenced by large-scale atmospheric circulation, inflow of waters from adjacent seas, bottom topography, tides, and other factors — all of which make it rather complicated and variable (Figure 2.3.1). Circulation is characterized by inflow of relatively warm Atlantic Water, and coastal water from the west. This inflow of Atlantic Water divides into two branches: 1) a southern branch that flows parallel to the coast and eastwards towards Novaya Zemlya; and 2) a northern branch that flows into the Hopen Trench. Coastal Water has more fresh-water runoff and a lower salinity than Atlantic Water; it also has a stronger seasonal temperature signal. In the northern region of the Barents Sea, fresh and cold Arctic Waters flows from northeast to southwest. Atlantic and Arctic water masses are separated by the Polar Front that is characterized by strong gradients in both temperature and salinity. There is large inter-annual variability in ocean climate related to variable strength of Atlantic Water inflow, and exchange of cold Arctic Water. Thus, there can be considerable seasonal variation in hydrographic conditions (Ozhigin et al., 2011).

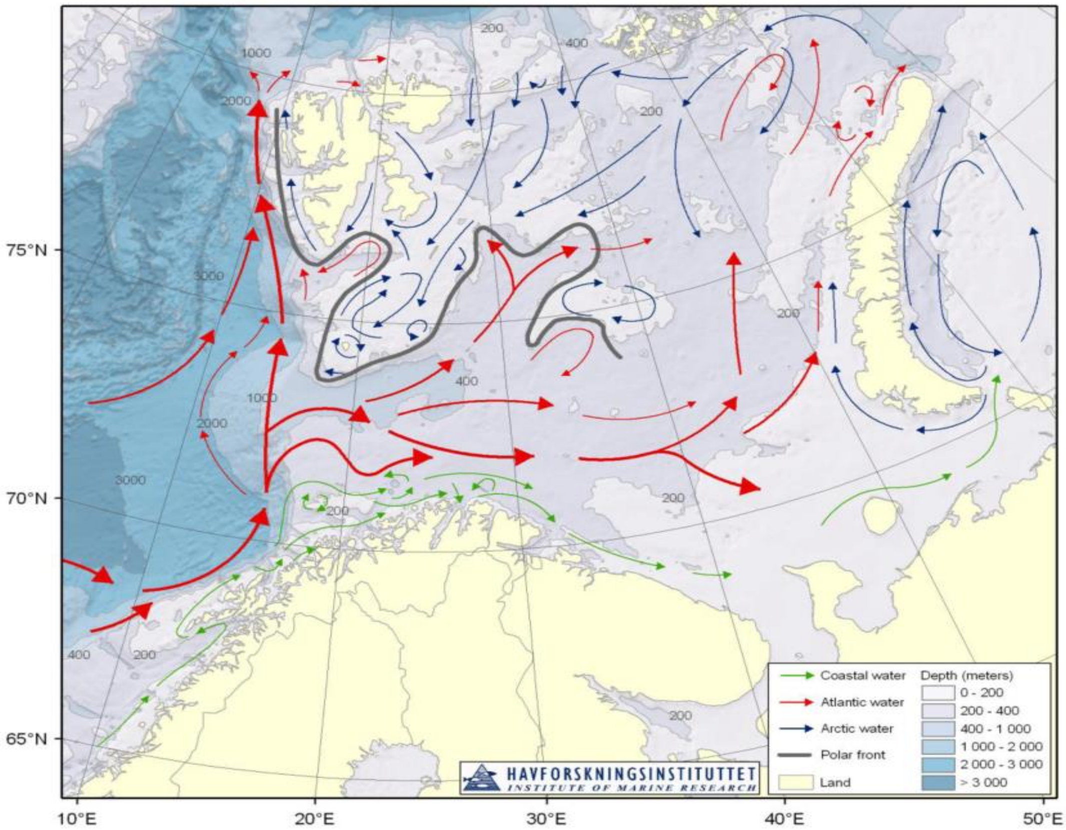


Figure 2.3.1. Main currents and water transport systems in the Barents Sea region.

Inflow from the Norwegian Sea takes place through the Bear Island Channel. Close to the coast low salinity (S = 34.4 pss) water of the Norwegian Coastal Current (NCC) carries a substantial fraction of runoff from the Baltic and the Norwegian coasts into the southern Barents Sea (Figure 2.3.1). It continues eastward as the Murman Coastal Current. Additional low salinity water is added as it passes the entrance to the White Sea and the mouth of the Pechora River, so the salinity remains low (S = 34.6 pss). Most of this ‘‘coastal’’ water passes into the Kara Sea through the Kara Gate. River runoff and net precipitation are small, and the NCC is the major freshwater source for the Barents Sea (Tantsiura, 1959; Loeng, 1991, 1992; Wassmann, 2006).

2.3.2.2 Stratification

Vertical stratification of different water masses within the Barents Sea is important for primary production. Different mixing regimes in Atlantic Water, the trench/Polar Front region, and the Melt Water/Arctic Water region are structured by different stratification mechanisms; this has implication for the phytoplankton community development and new production (Reigstad et al., 2002). Stratification of water masses in these regions may occur in several different ways: 1) through fresh surface water from melting ice along the marginal ice zone; 2) through solar heating of surface layers in Atlantic Water masses; or 3) through lateral dispersion of waters in the southern coastal region (Rey, 1981). Extensive ice formation, brine rejection in winter, and the subsequent melting of the ice in summer lead to a separation of the water column into a colder and denser deep-water, and a less saline, less dense upper layer. In the north, annual production is initiated by strong stratification developing as ice melts and light becomes available (Reigstad et al., 2002). Low salinity surface water contributes, together with inflows from the Arctic Ocean and the Kara Sea, to maintain stable stratification in the northern and eastern regions (Wassmann et al., 2006). In the central Barents Sea, ice that drifts over Atlantic Water is melted rapidly by heat from below, creating a thin, low-salinity layer and strong stratification over the Atlantic Water. This occurs throughout the year, and strong stability ensures a rapid phytoplankton bloom in the upper layer once sufficient light is present (Wassmann et al., 2006). Within the Atlantic Water, stratification is close to absent in spring, but weak stratification develops slowly from solar radiation during the summer (Reigstad et al., 2002).

2.3.2.3 Ice conditions

Ice conditions in the Barents Sea are influenced by both Atlantic and Arctic Oceans, and by atmospheric conditions. Typically, ice coverage is at a minimum in September, when an average of 5% of the Sea is ice-covered; while maximum ice cover is in April and ranges between 35% and 85%, with an average of 61%. Long-term yearly mean ice coverage is close to 40%. However, high seasonal variability in extent of the ice is characteristic. Inter-annual variability is also large, and the extent of ice varies widely depending on whether the winter is mild or severe. During winter, the ice-covered area expands from north to south and from east to west. By the end of winter the sea ice has reached its maximum thickness (130-150 cm). The ice edge retreats northward and eastward through September, most rapidly during June-July (Ozhigin et al., 2011).

2.4 Biotic components

2.4.1. Microbes

Y. Børsheim (IMR), and T. Shirokolobova (MMBI)

Typical of other ocean, 6 types of microbes (single-celled microorganisms) occur in the Barents Sea: Archaea; Bacteria; Viruses; Fungi; Protista; and Microbial Mergers. In biogeochemical cycles of the ocean, a multitude of processes are catalyzed by Bacteria and Archaea; functioning of these cycles in the Barents Sea do not differ qualitatively from those at lower latitudes. The carbon cycle serves well as an example of a biogeochemical cycle (Figure 2.4.1). Heterotrophic prokaryotes (denoted as bacteria for simplicity) are major degraders of dissolved organic carbon (DOC) — their principle source of energy and carbon. At high latitudes, DOC accumulates in the photic zone during the productive season; concentrations then decrease in September/October due to a combination of bacterial degradation and physical mixing processes (Børsheim and Myklestad, 1997; Børsheim, 2000). Primary production is the ultimate source of DOC, but all life processes contribute to the transfer of organismal carbon from primary producers into the pool of DOC (Børsheim et al., 2005). Grazing and predation produces fecal material which may be released as DOC, or occur as pellets. Fecal pellets typically sink to the seafloor to form sediments, but may also become dissolved in the water column as DOC. The Barents Sea is fairly shallow, and during winter the water column mixes from surface to bottom in many parts of the shelf basin. Thus, re-suspension of sediments and leaching of DOC accumulated in the sediments provides an additional source of DOC; this occurs primarily during winter. Figure 2.4.2 shows concentrations of DOC in the northern parts of the Barents Sea during July-August, 2007. Table 2.4.1 shows the depth distribution from the same expedition (Børsheim and Drinkwater, 2014).

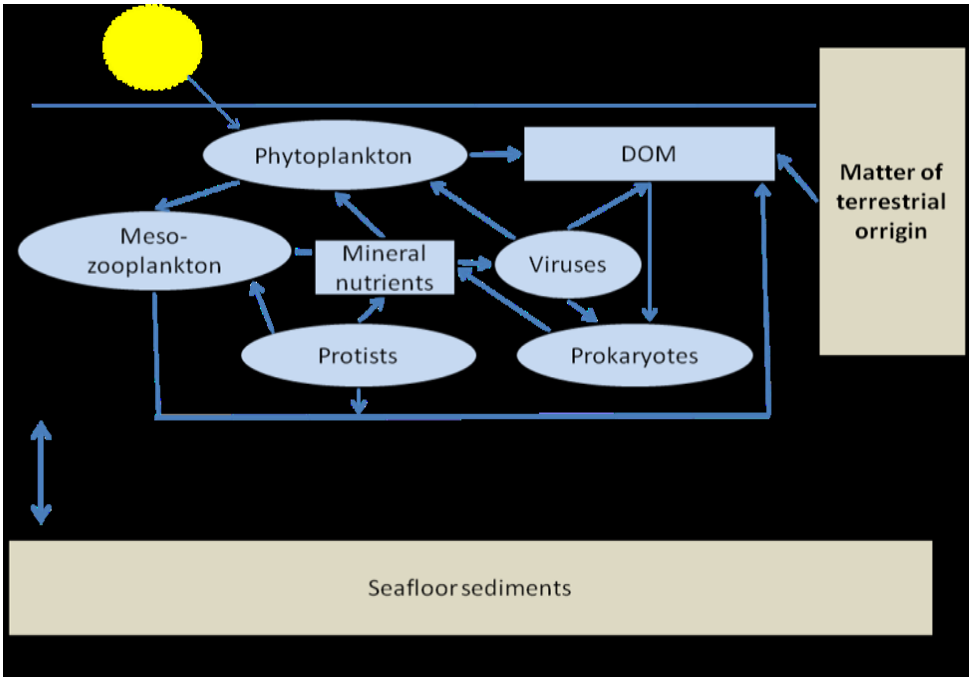


Figure 2.4.1. A box diagram showing major biochemical pathways for carbon in marine systems.

Total bacterial abundance in the south-eastern Barents Sea varies from $1.4 \cdot 10^5$ to over 10^6 cells ml^{-1}. Highest total bacterial abundance occurs in coastal areas and zones having water masses with different characteristics than open ocean waters. Profiles of total counts usually show increased abundance in the thermocline layer and bacterial biomass can vary during the year up to twice the mean value; maximal rates are observed during spring-summer, and minimal rates observed during autumn-winter (Baytaz and Baytaz, 1987, 1991; Teplinskaya, 1990; Mishustina et al., 1997).

Bacterial production rates have been measured in the Polar Front region (Table 2.4.2). Production rates were highest in warm Atlantic Water, but decreased rapidly northwards as temperatures decreased (Børsheim and Drinkwater, 2014).

Table 2.4.1. Depth distribution of total organic carbon (TOC), µM C ±standard deviation. Number of samples shown in parentheses.

Depth interval (m)	Atlantic water	Arctic water	Front, Atlantic	Front, Arctic
0-20	90.6±19.9(47)	73.8±8.5(56)	83.5±11.0(14)	86.1±8.1(21)
0-30	88.3±18.1(66)	73.5±8.2(92)	81.7±10.3(23)	84.2±9.4(34)
Below 30	69.8±17.6(116)	67.5±15.4(93)	71.6±8.1(37)	74.7±9.7(41
Below 50	69.5±18.9(98)	65.5±17.7(60)	71.2±8.1(32)	74.4±9.6(18)

Table 2.4.2. Depth distribution of bacterial production rates, mmol C m^{-3} day^{-1}.

Depth interval (m)	Atlantic	Front mainly Atlantic	Front mainly Arctic	Arctic
0-20	0.41±0.11	0.045*	0.18±0.055	0.062±0.047
0-30	0.32±0.18	0.050±0.025	0.15±0.068	0.060±0.042
Below 30	0.019±0.025	0.019±0.020	0.013*	0.028±0.0084
Below 50	0.010±0.011	0.012±0.006	0.013*	0.027±0.0071

*One measurement only

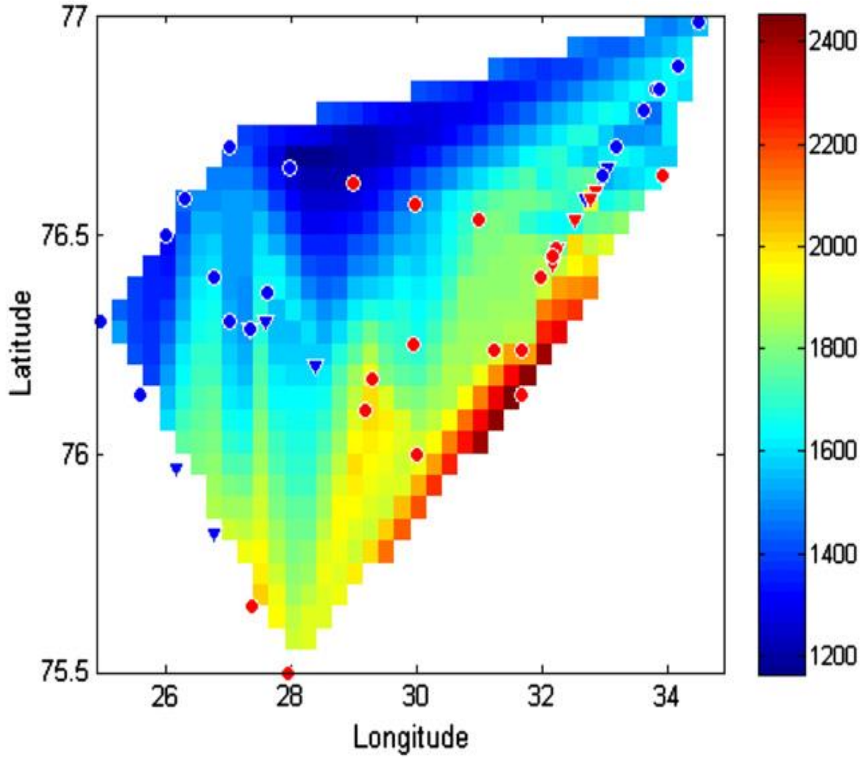


Figure 2.4.2. Distribution of TOC integrated over the upper 20 meters (mmol C m−2) at the Polar Front in the Barents Sea. Stations analyzed for TOC are labeled as: red circles = Atlantic Water; blue circles = Arctic Water; red triangles = Front with mostly Atlantic Water below a fresher layer; and blue triangles = Front but mostly Arctic Water.

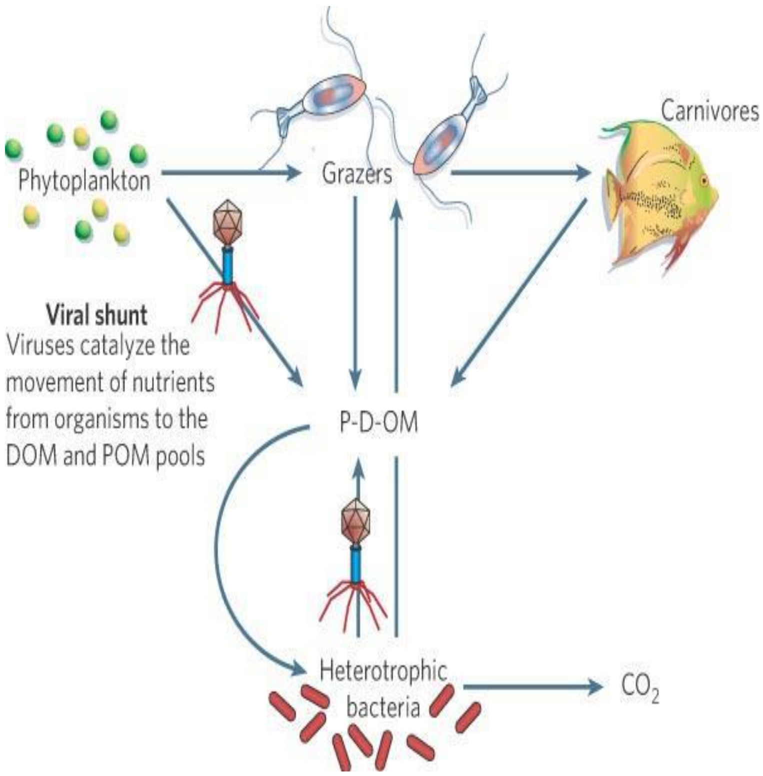


Figure 2.4.3. Illustration of key interactions between viruses and the ecosystem. Reprinted by permission from Macmillan Publishers Ltd: Nature C (Curtis A. Suttle, 2005) Viruses in the sea. Nature 437:365-361). Viruses short-circuit the flow of carbon and nutrients from phytoplankton and bacteria to higher trophic levels by causing the lysis of cells and shunting the flux to the pool of dissolved and particulate organic matter (D-P-OM). The result is that more of the carbon is respired, thereby decreasing the trophic transfer efficiency of nutrients and energy through the marine foodweb.

Parasitism by viruses also constitutes a source of DOC. This is illustrated by the reproductive cycle of lytic bacteriophages — viruses parasitizing bacteria (Figure 2.4.3). After infecting a bacterial cell and multiplying within that cell (at the cost of the bacterial metabolism), the host cell is destroyed allowing viral particles to be released into the water. As the cell breaks up, dissolved constituents are also released. Not only bacteria, but all other organisms from phytoplankton to mammals, are susceptible to viral attacks (Brussard et al., 2007; Frada et al., 2008; Marcussen and Have, 1992). Although bacteriophages have the extreme effect of completely destroying their hosts, the subsequent release of organic substances used by bacteria is a general consequence of viral infectivity.

For viruses, the probability of finding a host to infect depends on the hosts' concentration. For this reason, dense populations are more likely to undergo epidemic viral infections than sparse populations. This concentration effect on microbial population dynamics has been called the "killing the winner" hypothesis (Thingstad and Lignell, 1997). Populations which are successful at nutrient acquisition and fast growth increase their abundance, but with the consequence of also increasing propagation of their viral parasites. The logical inference of this hypothesis is that viruses are important to keeping high diversity.

The life-history strategy of viruses is believed to include the ability to seize genes from their hosts and from other viruses, and then incorporate them to benefit their own existence (Mann et al., 2005). In addition, genes from viruses are sometimes incorporated into genomes of their hosts. It is believed that such horizontal transfers of genes between non-related organisms are mediated by viruses, and that this is an important factor in evolution (Biers et al., 2008; Lang and Beatty, 2007). Some genes transported by viruses are associated with pathogenic properties, and have been studied extensively. The gene for toxin production in the bacterium causing cholera is carried by a virus, changing harmless cells of the common estuarine bacterium (*Vibrio cholera*) into an extremely potent pathogen in humans (Waldor and Mekalanos, 1996).

The sheer numbers of viruses are staggering; counted in a microscope numbers of viruses normally exceed numbers of bacteria by a factor of ten, approximately. Measured as genotypes, which is a fair proxy for species, there are more than 5,000 different types of viruses in 100 liters of seawater. In a kg of sediment, the number may approximate 1 million (Breitbart et al., 2002; 2004). Even more intriguing than the high diversity of viruses is the high diversity within their individual genomes. Clearly, every genotype consists of a variety of gene sequences with a variety of ages and origins (Dinsdale, 2008).

Both bacteria and viruses are highly variable and abundant in the Barents Sea (Figure 2.4.4). A sampling transect during midsummer showed that concentrations of viruses ranged from $5 \cdot 10^8$ to $6.4 \cdot 10^{10}$ particles-per-liter; while bacterial total counts varied from $4 \cdot 10^8$ to $6 \cdot 10^9$ cells·l-1 (Venger et al., 2012; Howard-Jones et al., 2002). Viral abundance co-varied to a fair degree with bacterial abundance, except for the station farthest north which was ice-covered (Table 2.4.3). In general, the dynamics of bacteria and viruses in this northern area do not differ from other parts of the Barents Sea, but the situation in northern ice-covered areas requires further investigation.

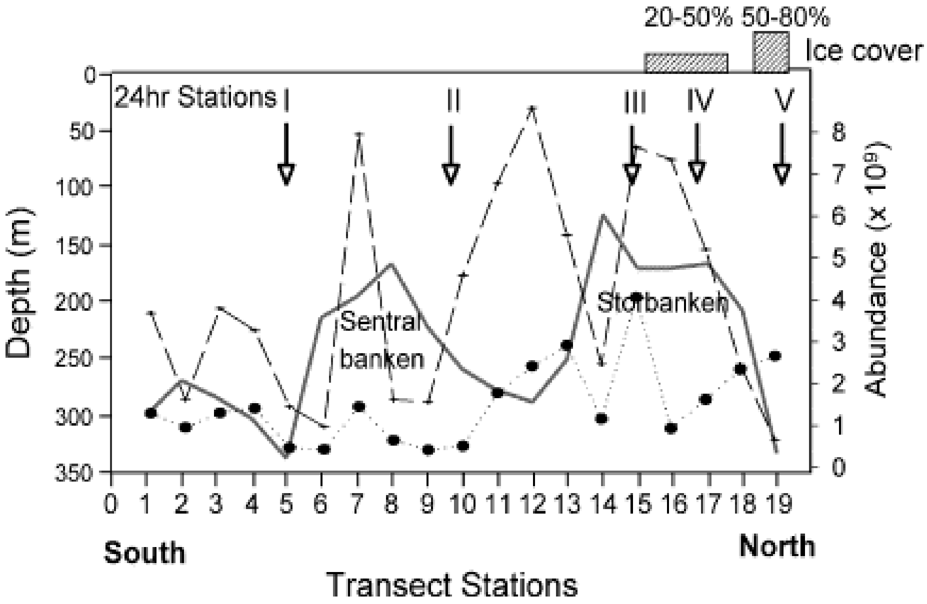


Figure 2.4.4. Results from a south to north transect in the Central Barents Sea during June-July 1999 (From Howard-Jones et al. 2002). Bacterial (●) and viral (–) abundance are presented as cells or VLP (virus-like particles) per liter across the Barents Sea. Stations 1–10 are at the southern and central Barents Sea, stations 11–14 are at the Polar Front, and stations 15–19 are ice-covered. Bacterial abundance was determined by DAPI (diamidino-phenylindole) staining; viral abundance with Yo-Pro. Error bars are standard deviations, n=3. The solid line represents bathymetry across transect.

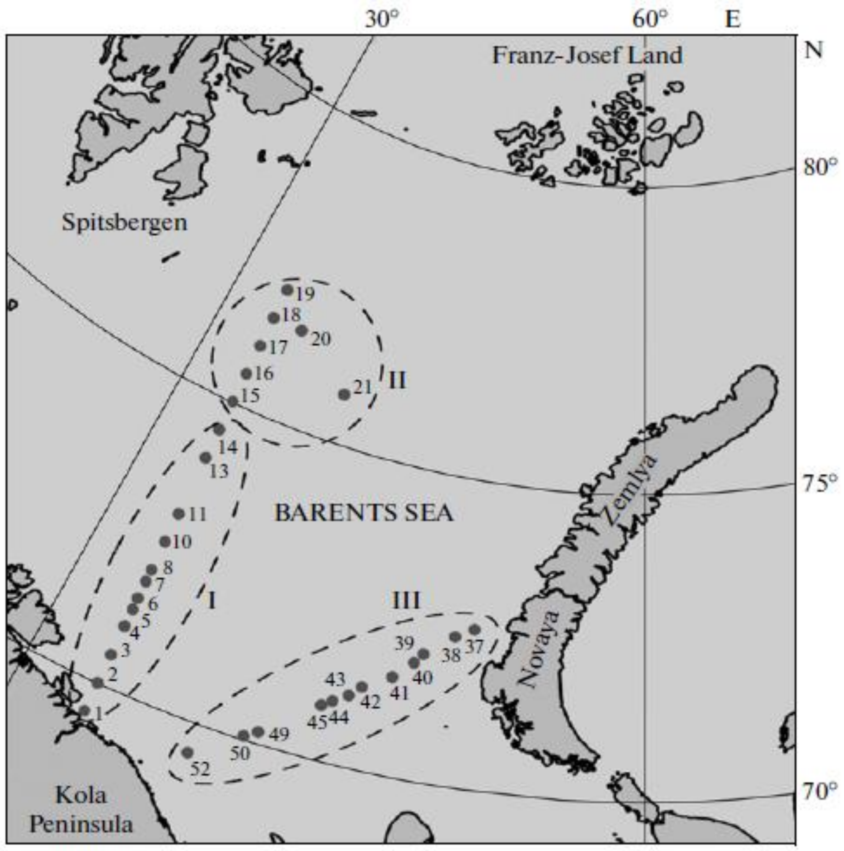


Figure 2.4.5. Stations sampled for viruses and bacteria in Barents Sea in August 2010. From Venger et al. 2012.

Table 2.4.3. Vertical profiles of water temperature and total counts of viruses and bacteria in the Barents Sea in August 2010. Location of the Stations is shown in Figure 2.4.5. From Venger et al. 2012.

Sampling area	Station	Depth. m	T	Viruses, N_V	Bacteria, N_B	N_V / N_B
II	10	0*	3.6	1.7	0.4	4.5
		75**	3.2	1.9	0.5	3.6
		140***	1.2		0.4	
	10	0	4.5	7.5	2.1	3.6
		65	4.4	4.3	0.3	12.6
		220	0.5		0.4	
	17	0	4.6	3.2	1.1	3.0
		60	4.2	3.3	0.6	5.8
		300	0.7	3.2	0.5	6.1
	18	0	2.4	3.6	0.9	3.9
		45	2.8	23.0	0.7	33.6
		210	0.7	3.1	0.5	6.6
	19	0	1.9		0.7	
		60	1.8	7.0	0.6	11.7
		160	0.5	3.3	0.4	9.1
	20	0	3.0	4.2	0.7	5.7
		50	3.0	8.1	0.6	13.9
		250	0.7	3.1	0.5	
	21	0	3.4	5.5	0.8	7.6
		35	3.2	3.4	0.4	7.9
		310	-0.2	2.9	0.5	5.6
III	39	0	4.7	25.1	3.4	7.4
		14	4.6	30.4	1.3	23.3
		210	2.6	6.6	0.3	19.4
	40	0	4.4	36.7	1.0	35.4
		50***	4.5	45.5	0.8	60.7
	42	0	4.5	64.1	1.9	33.0
		35	4.0	61.7	1.5	42.4
		70	1.4	19.0	0.7	29.1
	43	0	4.2	52.2	1.2	53.6
		33	3.7	50.0	1.0	52.2
		250	1.8	10.7	0.5	21.7

*The Surface layer. **The pyclocline. ***The near bottom layer

2.4.2 Phytoplankton

S.H. Larsen (IMR) and E. Druzhkova (MMBI)

The Barents Sea has a number of water masses with the relatively warmer and more saline (>35) Atlantic Water which flows through the southern part of the Barents Sea, and the colder, less saline (34.4-35) Arctic Water to the north. The boundary between these two water masses is marked by the Polar Front, and the different physical and chemical properties of these water masses influence the growth and development of the resident phytoplankton species (Loeng and Drinkwater, 2007). Seasonal changes in sea-ice formation and melt, freshwater inputs into coastal waters, and seasonal changes in solar radiation also result in the formation of stratified layers with different populations of phytoplankton compared to those lower in the water column. Recent declines in the extent, thickness, and duration of ice cover in the Northern Barents Sea are expected to result in a poleward movement of phytoplankton species, and earlier dates for initiation of the spring bloom in both open water and sea-ice algal communities (Wassmann, 2011).

Current phytoplankton gross primary production averages about 90 g C m^{-2} y^{-1} (± 19%) in the Barents Sea (Wassmann et al., 2006; Wassmann, 2011), with lower values (up to about 60 g C m^{-2} y^{-1}) found under northern and north-eastern sea-ice covered regions. However, there is much spatial and inter-annual variability due both to changing physical conditions and the occurrence of phytoplankton bloom-forming species (notably diatoms, and the prymnesiophytes: *Phaeocystis pouchetti* and *Emiliania huxleyi*). A review of estimates of gross primary production for different regions of the Barents Sea is provided by Wassmann et al. (2006). Gross primary production is more variable towards northern and eastern regions of the Barents Sea and least variable in the region north of Norway (Wassmann, 2011). The Norwegian Institute of Marine Research maintains two regular survey-sampling transects in the northern region: Fulgøya-Bjørnøya transect (FB) and Vardø-Nord transect (VN).

Species succession follows a general pattern during the growing season; however, there is much interannual variability along both these transects. The mean pattern for FB transect during 2008-2012 is shown in Figure 2.4.6. Cell numbers of all species are low in the winter period. With increasing solar radiation and stratification in the surface waters, phytoplankton numbers begin to increase in spring typically in coastal waters (Loeng and Drinkwater, 2007).

On average, diatoms form the first peak during April, followed by flagellate and ciliate species in May. A second peak of diatoms occurs during June-July, together with peak dinophyte and cryptophyte cell numbers. Late summer is characterized by high numbers of flagellate species (Rey, 2004).

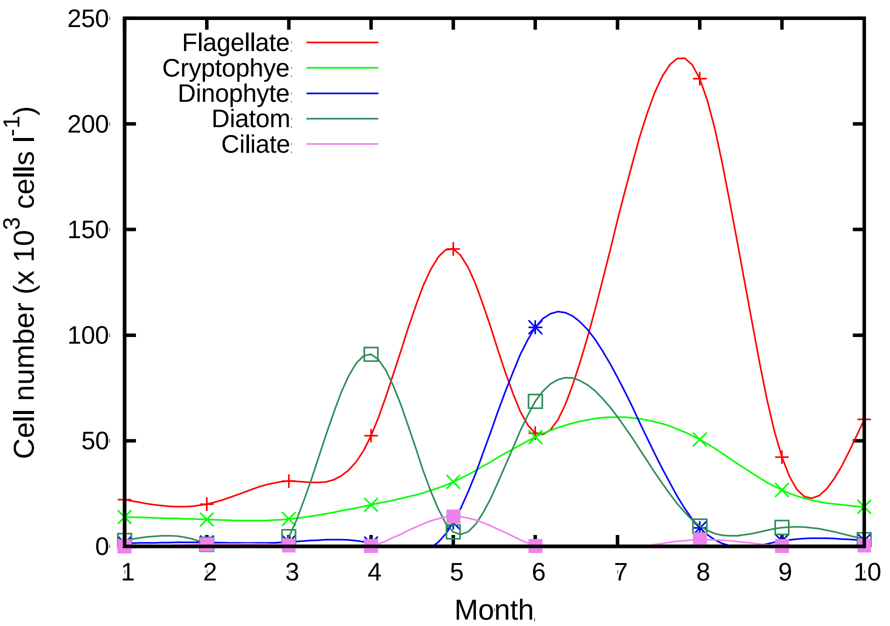


Figure 2.4.6. Annual mean pattern of species succession on the FB transect (2008-2012).

Phytoplankton species in the coastal pelagic zone tend to have a more complicated annual cycle compared to open shelf areas. For instance, monitoring by the Murmansk Marine

Biological Institute (MMBI) of subarctic coastal systems in the eastern Barents Sea shows two periods of peak abundance taking place; one in early spring and one in late spring. Moreover, once seasonal stratification has become established the summer stage sets in; this starts with a peak in early-summer and ends with another peak in autumn.

In these coastal waters, the start of spring phytoplankton activity (mid-March) is linked to the emergence of early-spring diatoms, namely *Thalassiosira hyalina (Grun.) Gran, T. cf.gravida Cl., Navicula pelagica Cl., N. septentrionalis (Grun.) Gran, Nitzschia grunowii Hasle,* and *Amphora hyperborea (Grun.)*. Cell abundance in this period is low and can range from several dozens to several hundred cells l^{-1}. The first spring maximum takes place in mid-April and occurs due to early-spring neritic arcto-boreal diatom species such as *Thalassiosira, Chaetoceros, Navicula,* and *Nitzschia*. Parameters measuring quantitative phytoplankton development reach maximums which are sustained over a few days. Phytoplankton abundance during early-spring bloom ranges from several hundred thousand to 2 million cells l^{-1}, and biomass ranges from 1 to 3 mg l^{-1}. During this period, the core of the phytoplankton community is concentrated in the upper 10-cm layer. Species forming the first maximum phytoplankton bloom are: *Thalassiosira cf. gravid*; *T. Nordenskioeldii*; *Chaetoceros socialis*; *C. furcellatus*; and *Navicula vanhoeffenii*.

The second spring maximum (late May to early June) is linked to freshwater runoff from surrounding land masses, date of initiation, quantitative characteristics, and qualitative structure varies from year to year, depending on when the maximum runoff takes place. In most cases, the phytoplankton activity repeats the first spring event, potentially with reduced number of dominants. However, in years with the low freshwater runoff, *Phaeocystis pouchetii* dominates in the bloom in the pelagic zone. The summer period (end of June – end of August) is marked with more of dinophyte microalgae in the phytoplankton community. The autumn succession cycle (from mid-September to early October) is usually associated to emergence of spring diatom forms in the pelagic zone. In this period, diatoms of the genus *Chaetoceros* and dinophytes of such genera as *Ceratium, Dinophysis, and Protoperidinium* dominate in the pelagic zone. Abundance does not exceed 2000 cells l^{-1} with biomass of less than 5 μg l^{-1}.

During the winter period (mid-November through mid-March), the entire phytoplankton community is in a dormant stage. Phytoplankton in the pelagic zone mainly consists of large oceanic dinophyte algae of cosmopolitan and arcto-boreal origin. Abundance ranges from several to dozens of cells l^{-1}. *Ceratium longipes, C. tripos, Dinophysis norvegica,* and *Protoperidinium depressum* form the core of the dominant complex.

2.4.3 Zooplankton

T. Knutsen (IMR), I. Berchenko (MMBI), P. Dalpadado (IMR), A. Dolgov (PINRO), S. Falk-Petersen (NPI), V. Nesterova (PINRO), I. Prokopchuk (PINRO), and A. Yurko(PINRO)

2.4.3.1 Crustacean zooplankton

In the Barents Sea ecosystem, zooplankton forms a link between phytoplankton (primary producers) and fish, mammals and other organisms at higher trophic levels. The most abundant zooplankton species — calanoid copepods, krill, and hyperiid amphipods — form the major diet of herring, capelin, polar cod, and juveniles of other fish species. The Arctic front in the Barents Sea marks the boundary between the mainly Arctic zooplankton species (*Calanus glacialis* and *Themisto libellula*) and the Atlantic/subarctic species (*C. finmarchicus, Meganyctiphanes norvegica, Thysanoessa* spp. and *Themisto* spp.).

Favorable conditions for the phytoplankton bloom/primary production at the ice edge as it retracts during summer and autumn, temporarily support large concentrations of crustaceans and other zooplankton species which become forage for seabirds, mammals, and fish. Blooms in Atlantic waters are not as intense as blooms at the ice edge; they occur over a longer period of time, however, and have higher total phytoplankton production. The spring bloom in Atlantic waters is of particular importance for reproduction of *Calanus finmarchicus* — the predominant herbivorous copepod in the central Barents Sea. It has an annual life cycle, and each new generation develops during spring and summer, being nourished by the seasonal phytoplankton bloom.

Among omnivorous zooplankton, krill (e.g. *Thysanoessa* spp.) are considered most important. *Thysanoessa inermis* and *T. longicaudata* dominate the central and northwestern Barents Sea, whereas distribution of *T. raschii* is restricted to shallow waters in the southeast region. Carnivorous zooplankton such as hyperiid amphipods (*Themisto* spp.) may feed on *C. finmarchicus*; as such, they compete with fish that consume zooplankton.

Herbivorous zooplankton in high latitude and ice-covered seas are exposed to large variations in food availability, not only between seasons (Lee and Hirota, 1973; Falk-Petersen et al., 2000b) but also between years, decades and longer periods (Falk-Petersen et al., 2007, 2009). Pelagic *Calanus* species — forming a major component of the Arctic marine foodweb — must, therefore, be adapted to an environment that changes markedly on different time scales. This readily accounts for the biodiversity within the *Calanus complex* in terms of different life strategies, different ecological niches, and different centers of distribution between different species.

The Arctic *Calanus* species (*Calanus finmarchicus*, *C. glacialis*, and *C. hyperboreus*) have an impressive plasticity. In the North Sea, *C. finmarchicus* can have a life span of less than a year (Wiborg, 1954; Marshall and Orr, 1955); while in the Norwegian Sea — along the coasts of northern Norway, Greenland, and east Canada, and the Barents Sea — the life span is mainly one year (MacLellan, 1967; Lie, 1968; Sekerak et al., 1976; Tande, 1991, Falk-

Petersen et al., 1999). *C. glacialis* may have a life span ranging from 1 to 3 years; however, in most areas a life span of 2 years is reported (Conover and Huntly, 1991; Kosobokova, 1999). *C. hyperboreus* shows the most impressive plasticity, with a life span ranging from two to five years (Dawson, 1978; Conover and Huntly, 1991; Hirche, 1997; Falk-Petersen et al., 1999, 2008).

Interconnected current systems in Atlantic and Arctic waters transport *Calanus finmarchicus*, *C. glacialis*, and *C. hyperboreus* long distances. These species are found distributed all over the Arctic, including the Norwegian Sea, the Barents Sea, the White Sea, the Arctic Ocean, the Greenland Sea, and in coastal waters bordering Siberia, East Canada and Alaska. However, these different species do originate from different centers of distribution, and are used as indicator species for the different water masses (Van Aken et al., 1991). The three *Calanu*s species also have different core areas for over-wintering, the Norwegian Sea being central for *Calanus finmarchicus*, the Arctic shelf area is central for *C. glacialis*, and the Greenland Sea and Arctic Ocean are central for *C. hyperboreus* (Jaschnov, 1970; Runge et al., 1986; Conover, 1988; Tande, 1991; Hirche and Mumm, 1992; Hirche and Kwasniewski, 1997; Hirche, 1997).

Despite the fact that the coastal Barents Sea (the Kola Peninsula coast) has a lower index of maximum biomass, the production potential of this area is considered to be relatively high. For example, maximum biomass in the 50 m surface layer — within the limits of 20 miles from the coast in the area from Kildin Island to the Svyatoy Nos Cape — has been estimated to be 1,300 mg/m^3 during July. In comparison, maximum biomass in the open Barents Sea has been estimated to be 2,000 mg/m^3 during a similar time of year (Kamshilov et al., 1958).

In a qualitative sense, the assemblage of zooplankton in the coastal area is characterized by the presence of more than 100 species, instars (stages between molts), and life-forms. Although only 20 of these species contribute significantly to total community biomass, their density is more than 100 individuals per m^3. *C. finmarchicus*, euphausiids, and species of *Metridia*, *Oithona*, *Pseudocalanus*, *Acartia*, *Temora*, and *Cladocera* are included in this category, as well as larvae from acorn shells and polychaetes (Kamshilov and Zelikman, 1958; Fomin, 1978, 1985).

Dynamic seasonal changes in zooplankton community structure occur. The period from March through the middle of May is characterized by rapid growth of meroplanktonic forms; most abundant among them are larvae of barnacles (*Cirripedia*) and polychaetes (*Polychaeta*). During this period, the presence of holoplanktonic organisms is noticeably lower than that of meroplanktonic forms. Gradual changes in the species' complex have taken place by the end of July. Holoplanktonic organisms — represented mainly by the copepods *C. finmarchicus*, *Pseudocalanus elongatus*, *Oithona similis*, *Acartia* sp., *Temora longicornis*, and *Microcalanus* sp. — become dominant. The end of June through August is the typical summer stage of seasonal community development. This stage typically has maximum biomass production during the year, and significant species diversity. During mid-August through September, the community gradually transitions into a climacteric state. This process is expressed by reduced quantities of zooplankton, gradual decreases in larval forms of bottom invertebrates in the pelagic zone, and cessation of growth for major copepods species. Winter stages of seasonal succession display a minimum biomass of holoplanktonic organisms, and an absence of benthic invertebrate larvae (Fomin, 1985; Druzhkov and Fomin, 1991).

In the Barents Sea ecosystem, zooplankton forms a link between phytoplankton (primary producers) and fish, mammals, and other organisms at higher trophic levels. The most abundant zooplankton species are calanoid copepods, krill, and hyperiids amphipods which are the major diet of herring, capelin, polar cod, and juveniles of other fish species. The Arctic Front in the Barents Sea marks the boundary between the mainly Arctic zooplankton species (*Calanus glacialis* and *Themisto libellula*) and the Atlantic/subarctic species (*C. finmarchicus*, *Meganyctiphanes norvegica*, *Thysanoessa* spp., *Themisto abyssorum* and *Themisto compressa*). Among omnivorous zooplankton, krill (e.g. *Thysanoessa spp*.) are considered most important. *Thysanoessa inermis* and *Thysanoessa longicaudata* dominate the central and northwestern Barents Sea, whereas distribution of *Thysanoessa raschii* is restricted to shallow waters in the southeast region. Carnivorous zooplankton such as hyperiid amphipods (*Themisto* spp.) may feed on *C. finmarchicus*; in so doing, they compete with fish that consume zooplankton.

Long-term monitoring data indicate substantial year-to-year variations in indices of biomass and abundance for zooplankton in the Barents Sea (Figure 2.4.7 and Figure 2.4.8). In Figure 2.4.7, the highest average biomass during this period was recorded in 1994 and 1995 with a minor peak in 2006. During 1988-1992, average zooplankton biomass was low relative to the estimated average value for the last 11 years. A comparable trend is reflected in data from the upper water column 0-100 m during the period 1988-2008 (not shown, as this series is now terminated). Data from 0-bottom m and 0-100 m indicate that by the period of the ecosystem survey (August-September) zooplankton have initiated their seasonal vertical migration to deeper water to overwinter. It is also apparent that smaller zooplankton (180-1000 μm size fraction) are most abundant at the 0-100m depth interval, and are more important in the upper water column during this time of the year. We observe particularly in 2008 that the biomass size-fraction 1000-2000 μm (bottom-0 m), which normally contains a substantially amount of the older *Calanus* stages, was significantly reduced compared to the previous years, while the 180-1000 μm size-fraction was considerably larger than observed during the two preceding years. This might suggest that the overwintering stock of *Calanus* in central- and western region of the Barents Sea was significantly reduced in 2008. During the last six years, the total size-fractionated biomass has been only slightly below the long-term mean (with the exception of 2012), but dropped markedly below the long-term mean in 2013. Also, the biomass in size-fraction 1000-2000 μm increased steadily from 2008, while a drop occurred in 2013 (Figure 2.4.7). It is noteworthy, that biomass in the largest size fraction (>2000 μm) has shown a decreasing from 2006 until the present.

Development of the Barents Sea krill stock (Figure 2.4.8) shows a moderately increasing trend over the last 10 years, with slightly less variation in the north-western area compared to the southern area. It is indeed interesting to compare this increase in abundance to the dietary preferences of capelin in various regions of the Barents Sea, which shows an increased importance of euphausiids in the capelin diet.

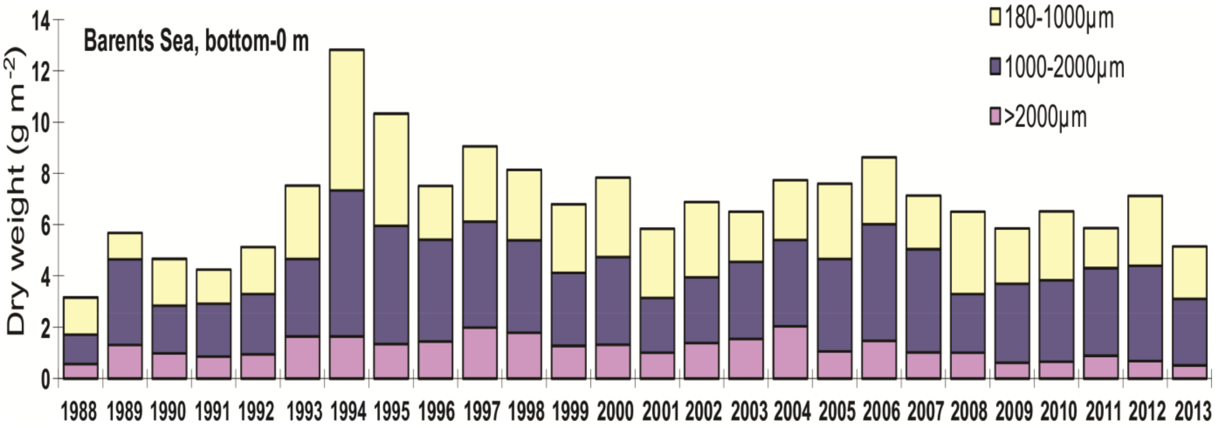


Figure 2.4.7. Long-term size composition of zooplankton biomass (WP2 net) in the water column (bottom to 0 meter depths) from the central-western part of the Barents Sea (Norwegian data only).

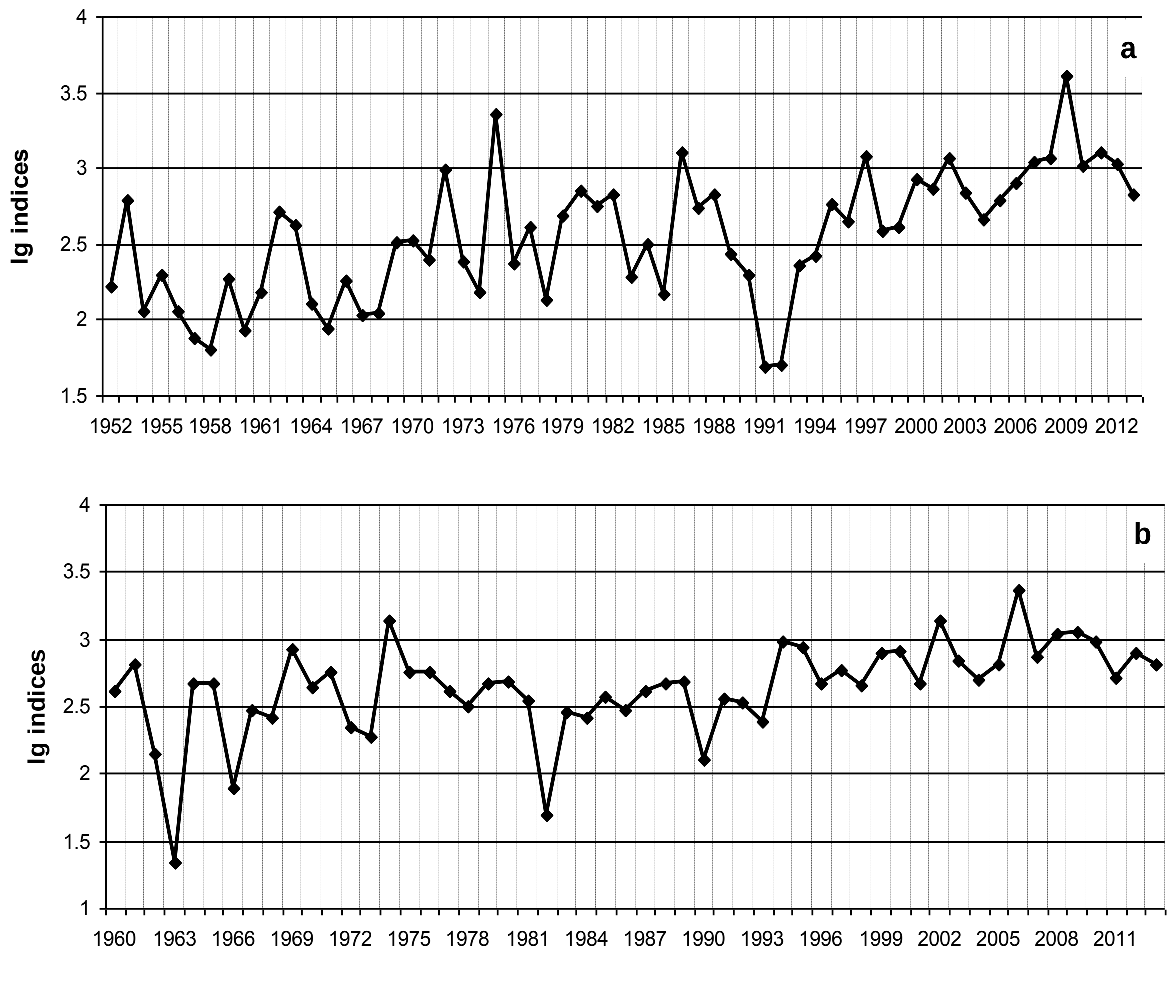


Figure 2.4.8. Variation in abundance indices of krill in southern (a) and north-western (b) regions of the Barents Sea (data from macroplankton survey conducted by PINRO).

2.4.3.2 Gelatinous zooplankton

Gelatinous zooplankton is a term often used by non-specialists in reference to classes of organism that are jelly-like in appearance. The term "jellyfish" is commonly used in reference to marine invertebrates belonging to the class *Scyphozoa,* phylum *Cnidaria*. Neither of these terms implies any systematic relationship to vertebrate fish. The term "jellyfish" is also often used in reference to relatives of true scyphozoans, particularly the *Hydrozoa* and the *Cubozoa*. In the Barents Sea ecosystem, however, comb-jellies (phylum *Ctenophora*) and cnidarians (phylum *Schyphozoa*) are the predominant species of "gelatinous zooplankton".

Both comb-jellies (*Ctenophora*) and "true" jellyfish are predators which may compete with plankton-eating fish, as copepods often are significant prey items for both groups. However, little is known about their prey and size preferences, or the succession of various groups of "jellyfish". Along with increased temperatures and changes in other components of the Barents Sea ecosystem, research interest has increased to understand how these changes effect the abundance and distribution of gelatinous zooplankton and their prey.

2.4.4 Benthos and shellfish

L.L. Jørgensen (IMR), S. Cochrane (Akvaplan NIVA), O. Lyubina (MMBI), P. Lyubin (PINRO), N. Anisimova (PINRO), P. Renaud (Akvaplan NIVA), J. Sundet (IMR), and T. Thangstad (IMR)

Benthic ecosystems in the Barents Sea have considerable value, both in direct economic terms, and in their ecosystem functions. Benthic fauna are an integral component of the ecosystem, and benthic processes are tightly linked to total system dynamics. A total of 3,245 faunal taxa have been recorded — of this total, benthic macrofauna (60%) and meiofauna (34%) make up the majority — and more than 3,050 species of benthic invertebrates inhabit the Barents Sea (Sirenko, 2001). A wide range of organisms are represented: some buried in sediment; others attached to a substrate; some slow and sluggish; others roving and rapid. Many feed by actively or passively sieving food particles or small organisms from the water. Others are detritus feeders eating bottom sediments, scavengers eating carrion, or carnivores actively hunting other animals. This diversity among bottom animals is believed due to the number of viable micro-habitats. In shallow waters, kelp forests form feeding and nursery habitats for many species of fish, birds, and mammals. Below the sublittoral zone, sea anemones, sponges, hydrozoans, tunicates, echinoderms, crustaceans, mollusks, and many other animal groups abound on hard substrates. These large conspicuous animals are not abundant on sand or muddy bottoms. In fact, some of these habitats may at first look rather lifeless. However, most benthic animals in these habitats live buried within the sediments. Polychaete worms, crustaceans, bivalves, and a number of other taxa are found in the sediments. Muddy areas often form habitat for dense aggregations of brittle stars, sea stars, or bivalves.

Iceland scallop (*Chlamys islandica*), northern shrimp (*Pandalus borealis*), red king crab (*Paralithodes camtschatica*), and snow crab (*Chionoecetes opilio*) are benthic residents which are harvested commercially. Many species of benthos are also interesting for bio-prospecting or as a future food resource, such as sea cucumber, snails, and bivalves. These species are intricate components of the ecosystem. Important fish species such as haddock, catfish, and most flatfishes primarily feed on benthos. Many benthic animals, primarily bivalves, filter particles and effectively clean oceanic waters. Others scavenge on dead organisms, returning valuable nutrients to the water column. Detritus feeders and other active diggers regularly move the bottom sediments around; thereby increasing sediment oxygen content and overall productivity – much like earthworms on land (ICES AFWG, 2014).

The benthic community is regulated by several factors, but multivariate analyses indicate that water depth and sediment type (i.e., predominant grain size) are consistent factors determining species composition of benthic fauna (e.g. Kendall, 1996; Dahle et al., 1998; Carroll et al., 2000). Our current understanding of benthic faunal patterns in the Barents Sea is based largely on bathymetric features and distribution of sediments. Characterization of the entire Barents Sea as a ‘‘shelf sea’’ tends to oversimplify the depth variation and bathymetric complexity of the region. Species diversity is relatively high compared to other Arctic seas, with the number of species steadily declining eastwards with distance from the North Atlantic; this trend is attributed to influence of the Arctic Ocean. Most (80%) of total benthic faunal biomass is attributed to 24 taxa, with 50% of that attributable to only 8 species (Wassmann et al., 2006).

Eight (8) squid species occur in the Barents Sea (Golikov et al., 2008). The flying squid (*Todarodes sagittatus*) was a significant fishery resource in Norwegian waters during several periods up about 1988 (Borges, 1990). However, since then this squid has almost been absent from our waters, and only sporadic catches have been recorded. *Gonatus fabricii* is another abundant squid species in off-shore waters of the Barents and the Norwegian Sea (Bjørke, 1995). This squid is important food for several bird and cetacean species, and also a potential fishery resource.

2.4.5 Fish

B. Bogstad (IMR), K.V. Drevetnyak (PINRO), I. Byrkjedal (UiB), A.V. Dolgov (PINRO), H. Gjøsæter (IMR), E. Johannesen (IMR), S. Mehl (IMR), Å. Høines (IMR), M.S. Shevelev (PINRO), and O.V. Smirnov (PINRO)

2.4.5.1 Species diversity and zoogeography

Recent data indicate that more than 200 fish species representing 70 families occur in the Barents Sea (Dolgov, 2004; Bogstad et al., 2008). Predominant families are: eelpout (Zoarcidae); snailfish (Liparidae); codfish (Gadidae); sculpin (Cottidae); flatfish (Pleuronectidae); and rockling, ling, and tusk (Lotidae). These families account for nearly 80% of species regularly occurring in the Barents Sea, and more than 40% of species recorded in this region (Dolgov et al., 2011). Around 100 fish species appear regularly in trawl catches during scientific surveys.

Different fish species are not evenly distributed in the Barents Sea; rather, species' abundance is highest in areas with preferred environmental conditions. Distribution of species caught during ecosystem and winter surveys has been mapped in an Atlas of the Barents Sea Fishes (Wieneroither et al., 2011, 2013). Different water masses — Coastal Water, Atlantic Water, Arctic Water, and frontal zones between these water masses — are important determinants of distribution and abundance for fish species. Depth is also an important determinant for demersal fishes (Johannesen et al., 2012); while distribution of zooplankton is an important determinant for pelagic species.

Andriashev and Chernova (1995) classified 166 fish species inhabiting the Barents Sea into seven zoogeographical groups based on their distribution and water-mass association: Arctic; Mainly Arctic; Arctoboreal; Mainly Boreal; Boreal; South Boreal; and Widely Distributed (Table 2.4.4); 107 of these species occur regularly (Figure 2.4.9), and all species classified as Arcto-boreal and Mainly Boreal occur regularly. Arctic species have the southern extent of their distribution in areas north of the Polar Front. Some Arctic species inhabit deep waters of the polar basin, and 80% of recorded Arctic species occur regularly. For species classified as Boreal and South Boreal the northern extent of their distribution is in the Barents Sea; 50 % of these species occur regularly. Less than 10% of Widely Distributed species occur regularly, and thus may be considered short-term residents.

Table 2.4.4. Definition of zoogeographical fish groups.

Zoogeographical group	Definition (cited from Andriyashev and Chernova 1995)
Arctic	Species which continuously live and reproduce in Arctic waters. These include Arctic deepwater species (bathyal and abyssal), the so-called Scandinavian endemic Arctic Fauna.
Mainly Arctic	Species which are usually found in Arctic waters but which also occur in adjacent boreal waters
Arcto-boreal	Species which are distributed in the Arctic and in boreal waters
Mainly Boreal	Species characteristic of boreal waters but common also in the boundary regions of the Arctic
Boreal	Species characteristic of boreal waters but only rarely and temporarily occurring in the bordering regions of the Arctic
South Boreal	This conditional category refers primarily to the Atlantic boreal subtropic (usually pelagic) species
Widely Distributed	Species common not only in the boreal and subtropical zone, but also in the warm waters

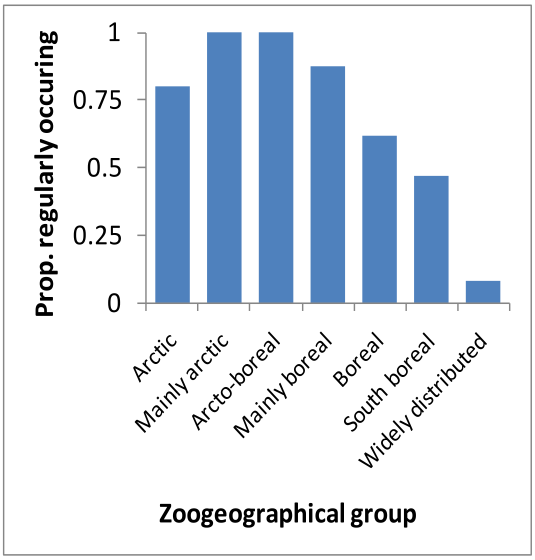


Figure 2.4.9. Proportion of fish species recorded in the Barents Sea (n=166) from Andriyashev and Chernova (1995) that are regularly occurring (n=107) classified by zoogeographical groups.

2.4.5.2 Main fish species – stock size and fluctuations

Principal demersal stocks of commercial importance in the Barents Sea include: Northeast Arctic cod (*Gadus morhua*); haddock (*Melanogrammus aeglefinus*); redfish (mainly deep-sea redfish, *Sebastes mentella*); Greenland halibut (*Reinhardtius hippoglossoides*); long rough dab (*Hippoglossoides platessoides*); wolfish (*Anarhichas lupus*); and European plaice (*Pleuronectes platessa*). Analytical assessments have not yet been conducted for long rough dab, wolffish, and plaice. Major pelagic stocks include: capelin (*Mallotus villosus*) and polar cod (*Boreogadus saida*); in western and southern parts of the Barents Sea, immature Norwegian Spring-Spawning herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*) are also important. All these species have varied significantly in abundance due to a combination of fishing pressure and environmental conditions (Figures 2.4.10 and 2.4.11). Until the 1970s, deep-sea redfish was abundant in the Barents Sea. However, due to overfishing of this long-lived slow-growing species, the stock declined dramatically during the 1980s and remained at low levels until recent signs of recovery.

There is significant interannual variability in recruitment patterns of Barents Sea fish species (Figure 2.4.12). Contributing factors include: spawning stock biomass; climate conditions; food availability; predator abundance; and distribution. Variation in recruitment of some species, including cod and herring, has also been associated with changing inflow of Atlantic Water into the Barents Sea.

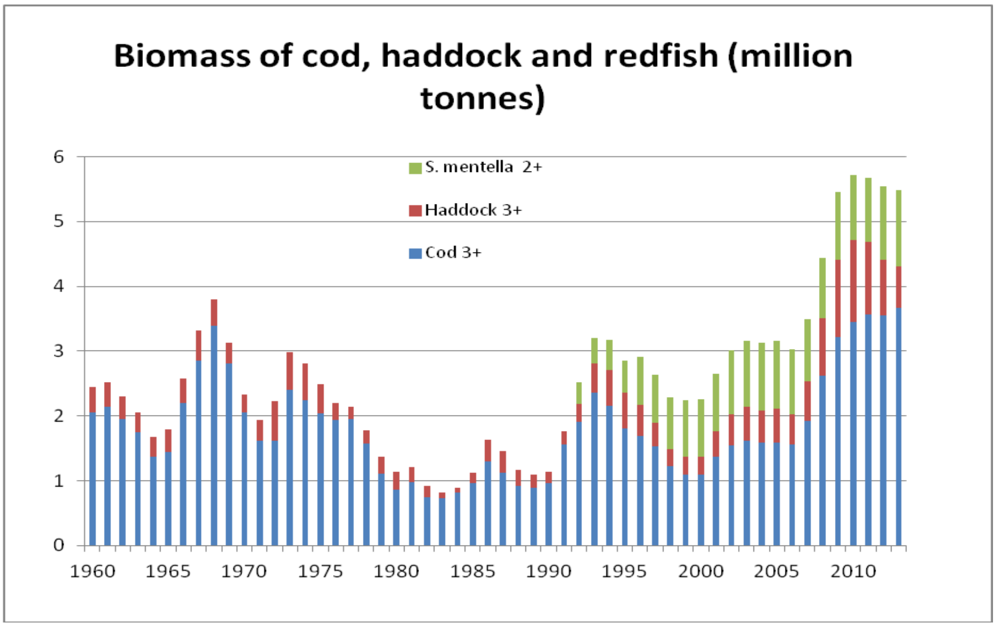


Figure 2.4.10. Biomass of the most abundant demersal fish species in the Barents Sea (ICES AFWG, 2014). Data are taken from: cod VPA estimates; age 3+ haddock VPA estimates; age 3+ *Sebastes mentella* VPA estimates, age 2+ (only available from 1992 onwards).

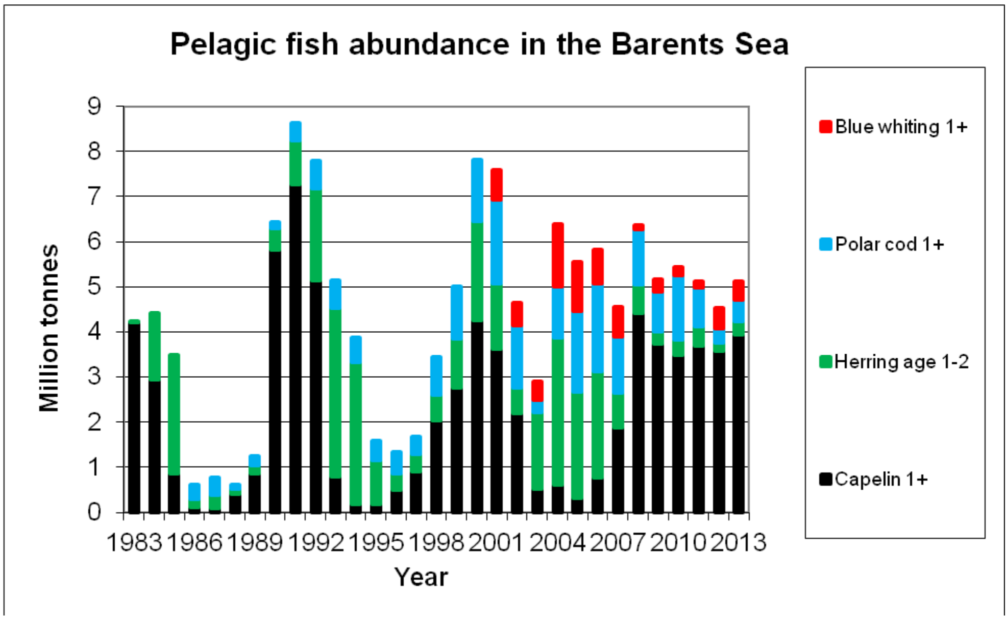
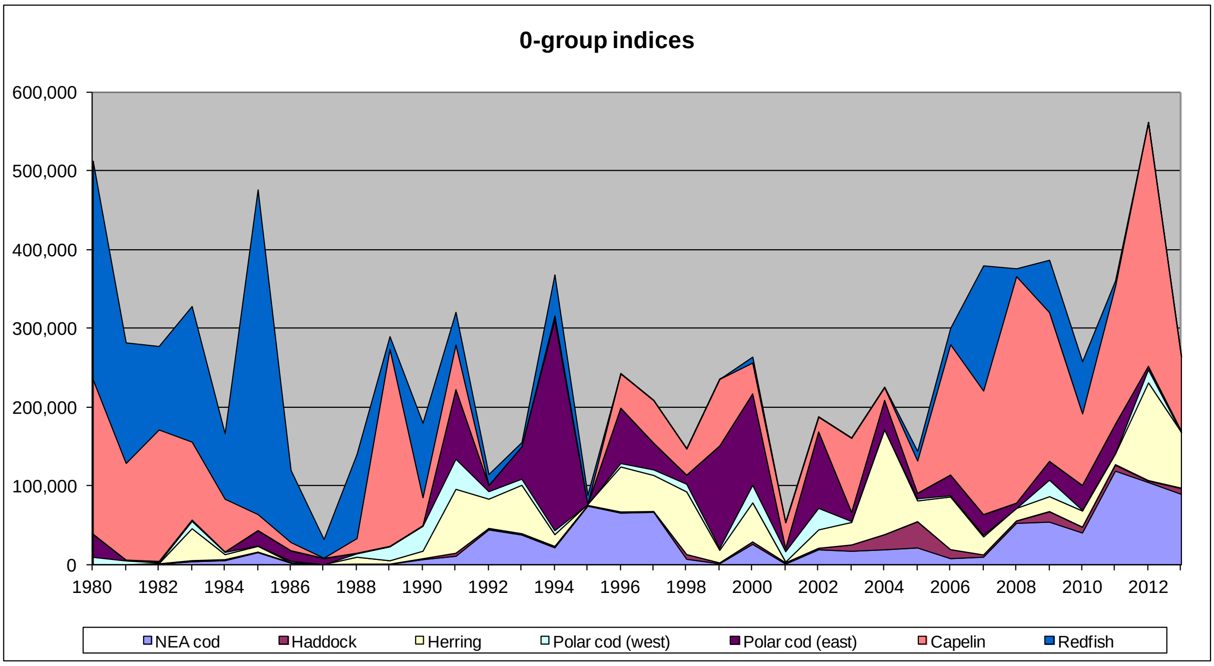


Figure 2.4.11. Biomass of pelagic fish species in the Barents Sea. Data are taken from; capelin: Acoustic estimates during September-October, age 1+ (ICES AFWG, 2014); herring: VPA estimates of age 1 and 2 herring (ICES WGWIDE, 2014) using standard weights at age (10 g for age 1 and 44g for age 2); polar cod: Acoustic estimates in September-October, age 1+ (Anon., 2014); blue whiting: Acoustic estimates in September-October, age 1+ (Anon., 2014). Polar cod estimates are only available from 1986 onwards and blue whiting estimates from 2001 onwards.



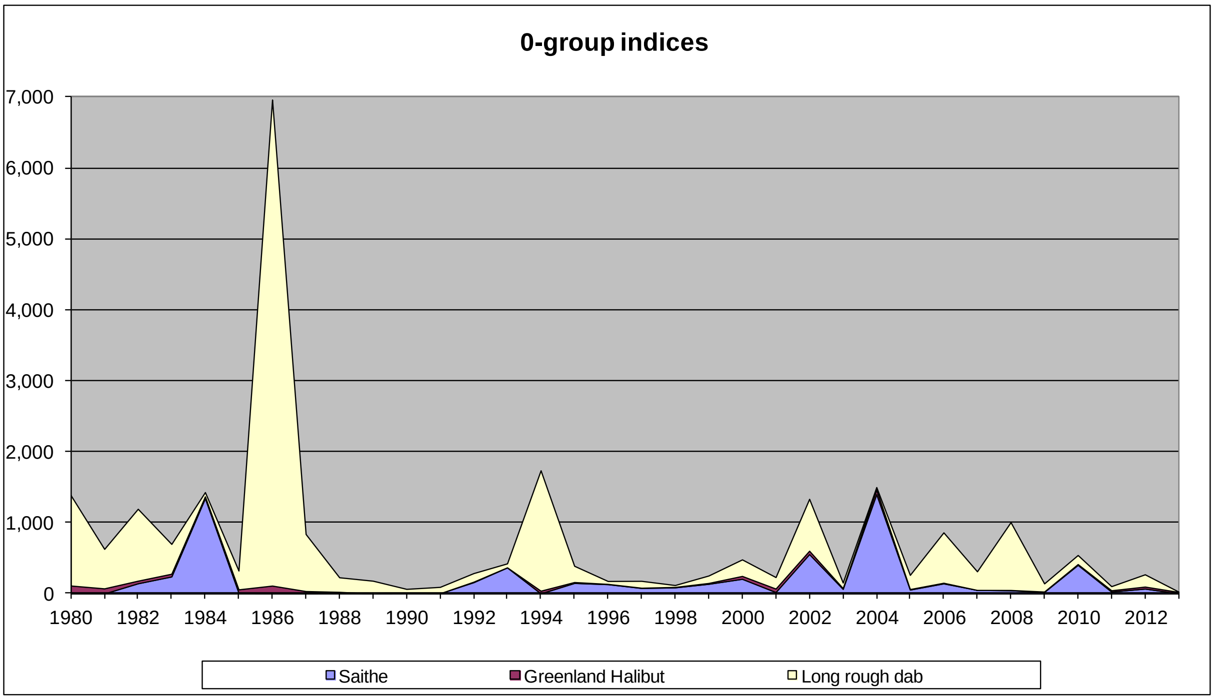


Figure 2.4.12. (Includes the 2 figures preceding) 0 age-group abundance indices (in millions of individuals) not corrected for catching efficiency. Note that the vertical axes differ between the two panels.

Cod *(Gadus morhua)*

Adult Northeast Arctic cod undertake annual spawning migrations from the Barents Sea to the western coast of Norway (2.4.13). Spawning occurs largely in the Lofoten area during March-April. Cod larvae are then advected via the Norwegian coastal current and the Norwegian Atlantic current back to the Barents Sea where they settle at the bottom around October. Cod is a keystone species and the most important predatory fish in the Barents Sea. It feeds on a wide range of prey, including: larger zooplankton species; most available fish species; and shrimp. Cod prefer capelin as prey, and feed on them heavily as they migrate into southern and central regions to spawn. Capelin stock fluctuations strongly effect cod growth, maturation, and fecundity; they also indirectly affect cod recruitment, as cod cannibalism is reduced during years with high capelin biomass. Euphausiids are also important prey for cod during the first year of life (Ponomarenko, 1973, 1984); in years when the capelin stock is low, cod predation on euphausiids increases (Ponomarenko and Yaragina, 1990). Along Norway's coast, coastal cod is fished together with Northeast Arctic cod. The TAC for Norway includes both coastal cod and Northeast Arctic cod. Catches are separated by type of cod based on the structure of otoliths sampled from the commercial fishery.

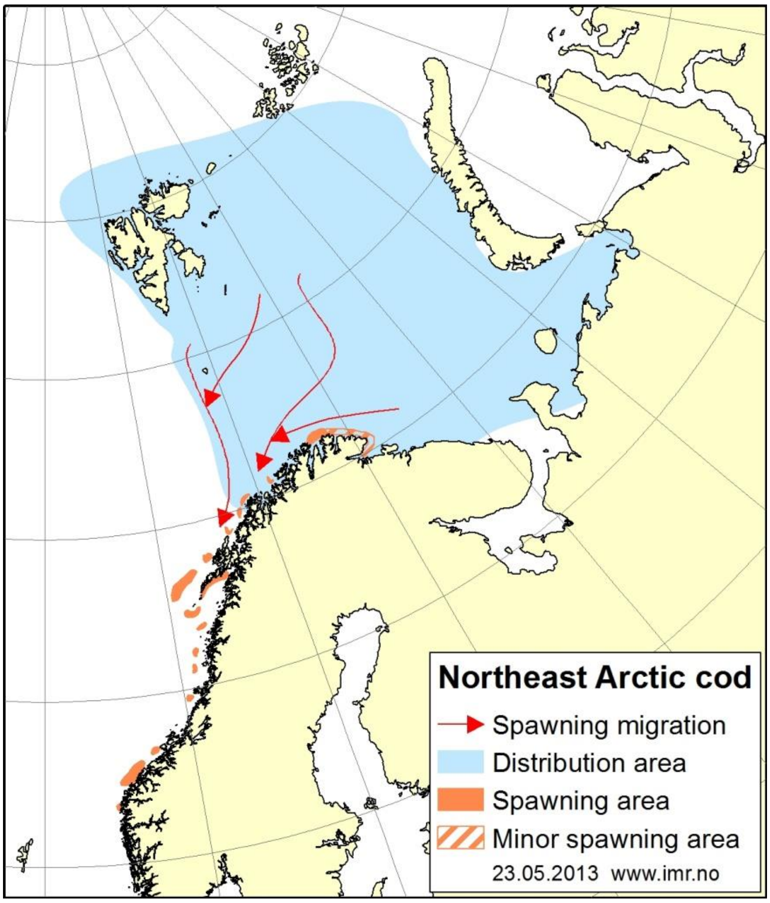


Figure 2.4.13. Distribution area for Northeast Arctic cod.

Haddock *(Melanogrammus aeglefinus)*

Haddock is an important demersal gadoid species that undertakes extensive migrations to and from its spawning grounds in the Barents Sea (Figure 2.4.14). Variation in haddock recruitment has been associated with changing inflow of Atlantic Water to the Barents Sea. Water temperature during the first and second years of the haddock life cycle is an indicator of year-class strength; if mean annual bottom water temperature does not exceed 3.8°C during this period the probability of having a strong year class is low, even if other factors are favorable. Water temperature is not a consistent determinant of year-class strength; however, a steep rise or fall in water temperature can have a marked effect. Haddock feed primarily on relatively small benthic organisms, including crustaceans, mollusks, echinoderms, worms, and fish. They are omnivorous, however, and also feed on plankton. During capelin spawning, haddock prey on capelin and their eggs. When capelin abundance is low, or when their areas of distribution do not overlap, haddock may switch to other species, i.e. young herring, euphausiids, or other benthic organisms (Zatsepin, 1939; Tseeb, 1964). Haddock stock size shows large natural variation, largely due to fluctuations in year class strength. Similar to cod, annual consumption of haddock by marine mammals (primarily seals and whales) depends on the availability of capelin. During years when the capelin stock is large, the importance of haddock in the diet of marine mammals is minimal; when the capelin stock is reduced, the proportion of haddock consumed by marine mammals tends to increase.

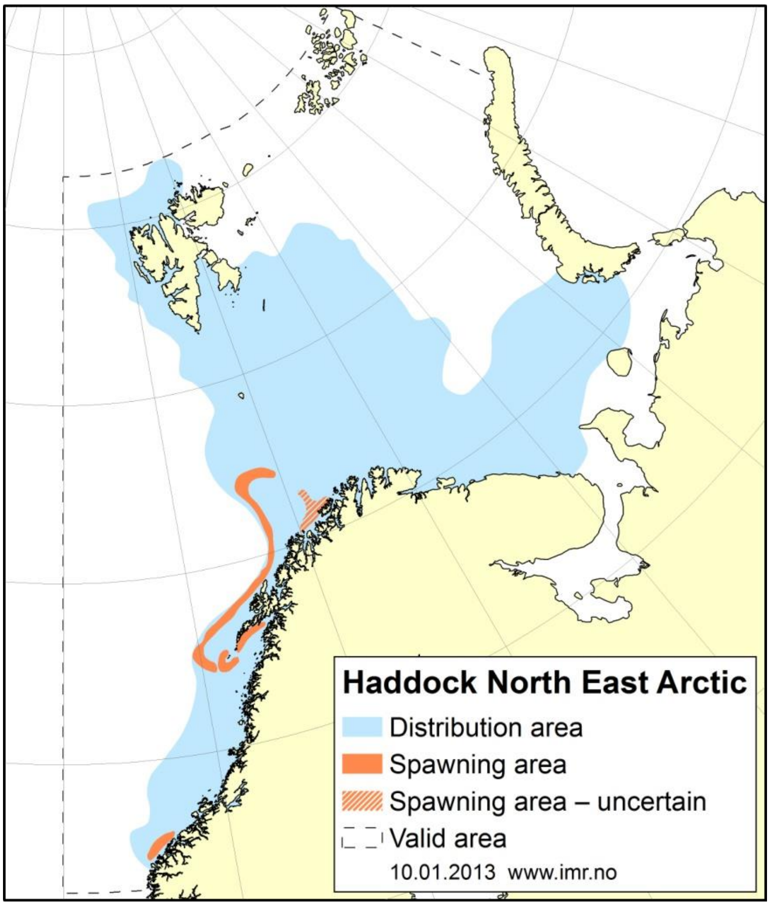


Figure 2.4.14. Distribution area for Northeast Arctic haddock.

Redfish *(Sebastes mentella and Sebastes norvegicus)*

Deep-sea redfish (*S. mentella*) and golden redfish (*S. norvegicus*) have traditionally been important commercial species in the Barents Sea ecosystem; current stock levels, however, have been severely reduced. Young redfish are plankton eaters (Dolgov and Drevetnyak, 1995); larger individuals consume larger prey, including other fish species (Dolgov and Drevetnyak, 1993). Until 1990, huge amounts of post-larval redfish filled pelagic waters of the Barents Sea during summer and autumn (Figure 4.2.15). These 0 age-group redfish consumed plankton, and were consumed by other larger fish. Whether this niche once filled by redfish has been filled by other plankton feeders is not well understood. Since redfish are viviparous and give birth to live larvae, a strong relationship is assumed between age composition of the spawning stock and levels of recruitment. In the Barents Sea, low abundance of larval and juvenile redfish is believed to indicate low spawning stock size. Fisheries for both these species are currently restricted in order to rebuild spawning stock size; this is expected to improve conditions and lead to increased production.

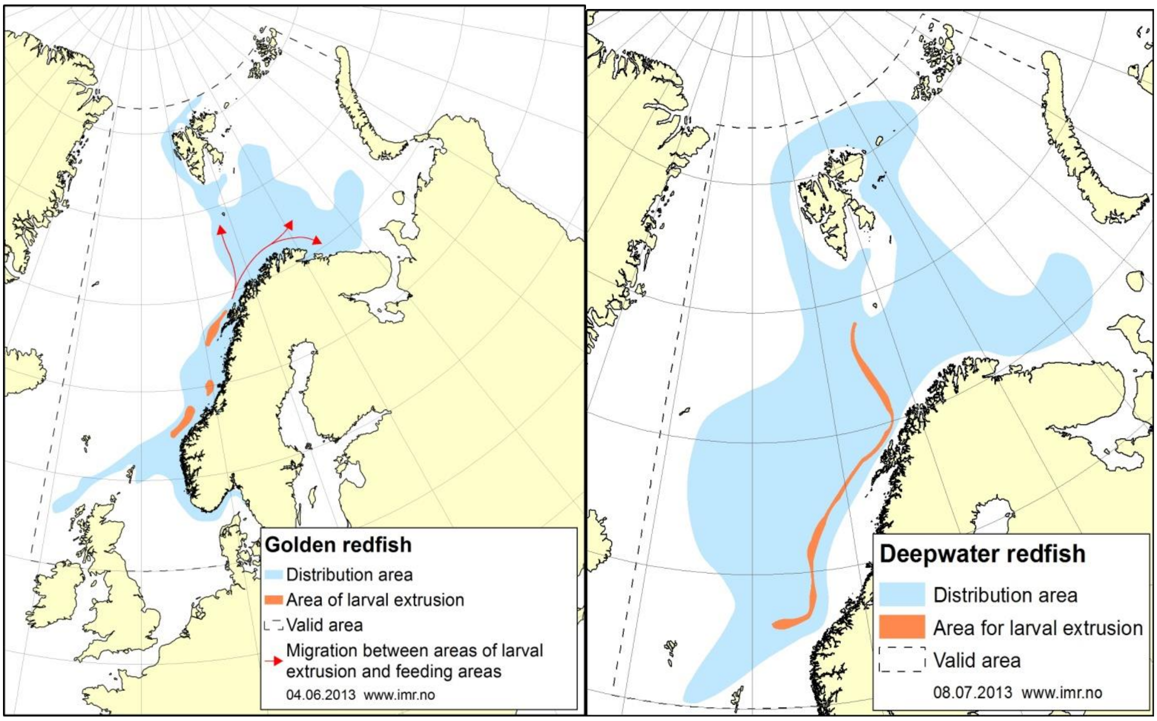


Figure 2.4.15. Distribution area for golden redfish (left) and deep-sea redfish (right) and in the Barents Sea region.

Greenland halibut *(Reinhardtius hippoglossoides)*

Greenland halibut is a large piscivorous flatfish that has the continental slope — between the Barents Sea and the Norwegian Sea — as an important area for adults; it is also found in the deeper waters of the Barents Sea (Figure 2.4.16). Investigations during the period 1968-1990 indicated that cephalopods (squids, octopuses) and fish (mainly capelin and herring) predominated in Greenland halibut stomachs (Nizovtsev, 1975; Shvagzhdis, 1990; Michalsen and Nedreaas, 1998; Dolgov, 2000). With increasing predator length, ontogenetic shifts in prey preference were evident; decreasing proportions of small prey (shrimps and small capelin), and increasing proportions of larger fish. The largest Greenland halibut sampled, at lengths more than 65-70 cm, primarily had cod and haddock as stomach contents.

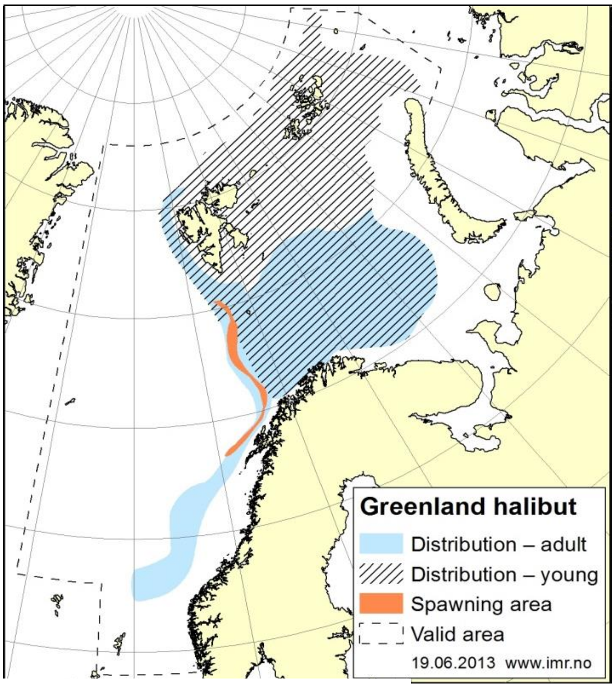


Figure 2.4.16. Distribution area for Northeast Arctic Greenland halibut.

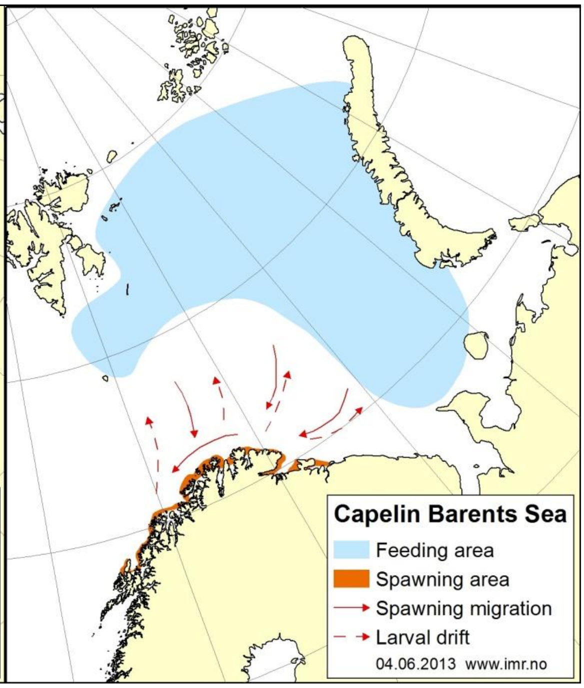


Figure 2.4.17. Distribution area for Barents Sea capelin.

Capelin *(Mallotus villosus)*

Capelin is a key species because it feeds on zooplankton near the ice edge, and is typically the most important prey species for top predators in the Barents Sea. In this way, it serves as a major transporter of biomass from the northern Barents Sea to the south (Hamre, 1994). During summer capelin migrate northward as the ice retreats; there they have continuous access to new zooplankton production zones uncovered by melting ice. They often reach 78-81˚N by September-October, before beginning their southward migration to spawn on northern coasts of Norway and Russia. During spawning migrations capelin are preyed upon extensively by cod, other piscivorous fish species, several species of marine mammals, and birds (Figure 4.2.17) (Dolgov, 2002).

Abundance of young herring in this area has an effect on capelin recruitment. It is reported that when large year classes of herring enter the Barents Sea, the following year's capelin recruitment is usually poor, and the subsequent year's capelin stock is likely to collapse (Gjøsæter and Bogstad, 1998). In recent years, capelin recruitment and stock size has been at an intermediate level; likewise, biomass of young herring in the area has been at an intermediate level.

Herring *(Clupea harengus)*

Herring spawn along the western coast of Norway; larvae are then transported northward to coastal areas of the southern Barents Sea, and into some Norwegian fjords. Juveniles are distributed in southern parts of the Sea, which serve as nursery areas for approximately three years before they migrate west and south along the Norwegian coast to join the adult stock (Figure 4.2.18). In the south-eastern Barents Sea, both Norwegian spring-spawning herring and local herring stocks (Cheshko-Pecherskaja herring) are found. These two species can be distinguished by counting the number of vertebrae. In acoustic estimates of young herring in this area, the proportion of each stock is determined separately for each WMO (World Meteorological Organization) square (1° latitude x 2° longitude).

Polar cod *(Boreogadus saida)*

Polar cod is a cold-water species largely inhabiting eastern and northern regions of the Barents Sea. It spawns in both the south-eastern area and the area east of Spitsbergen (Figure 2.4.19). It is important prey for several marine mammals, but also for Arctic cod (Orlova et al., 2001). Polar cod is semi-pelagic and inhabits the lower water column. It is a plankton feeder, with a rather short life cycle; fish older than 5 years are rarely found. Presently, there is little commercial fishing on this stock.

Blue whiting *(Micromestisius poutassou)*

In the northeast Atlantic region, blue whiting is mainly distributed in the Norwegian Sea (Figure 2.4.20). The marginal northern extent of its distribution is at the entrance to the Barents Sea; its population there is relatively small. During years with inflow of warm Atlantic Water masses, blue whiting may enter the Barents Sea in large numbers; they can be a predominant species in western areas. Such a situation occurred during 2000-2001, and blue whiting abundance remained significant until 2007. During its early life history (until age 5), this species is primarily a plankton feeder; its diet later become more piscivorous.

Blue whiting, capelin, polar cod, and young herring are largely plankton feeders. General distribution patterns for these four species have only minimal overlap: blue whiting in the west; capelin in the north; polar cod in the east (some overlap in the Spitsbergen region); and herring in the south. In the south-western region, blue whiting and herring may overlap in areas of distribution, but they tend to occupy different depths in the water column. Their lack of overlap with other predominant pelagic species — both in area of distribution and depth in the water column — suggests low interspecies competition in feeding on the local zooplankton.

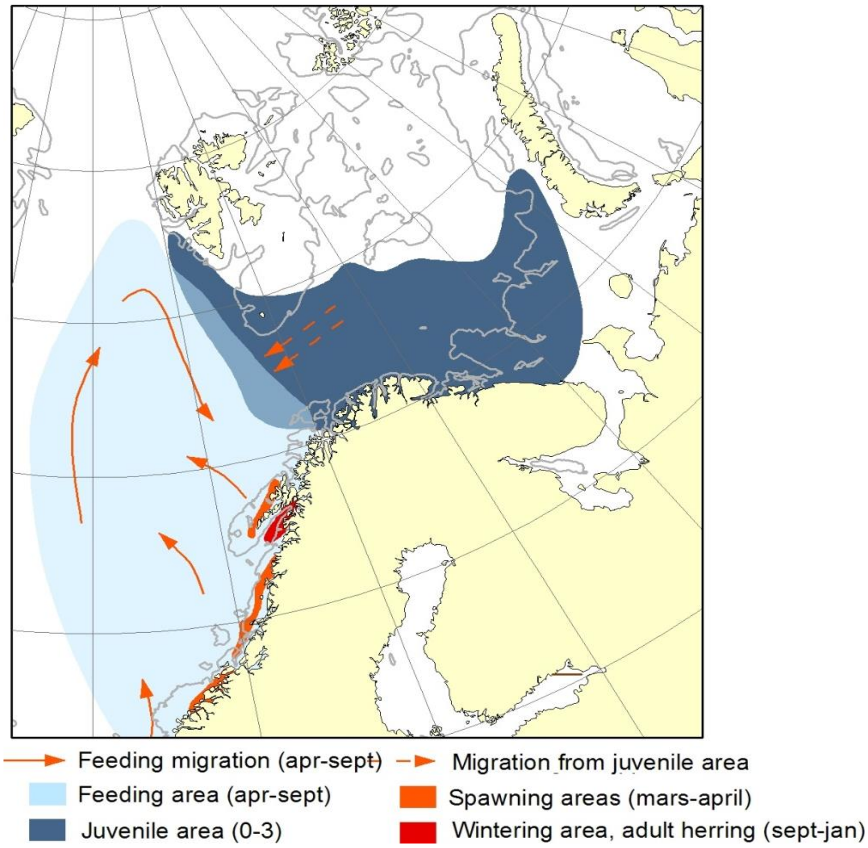


Figure 2.4.18. Distribution area for Norwegian spring-spawning herring during its life cycle (Belikov et al., 2004).

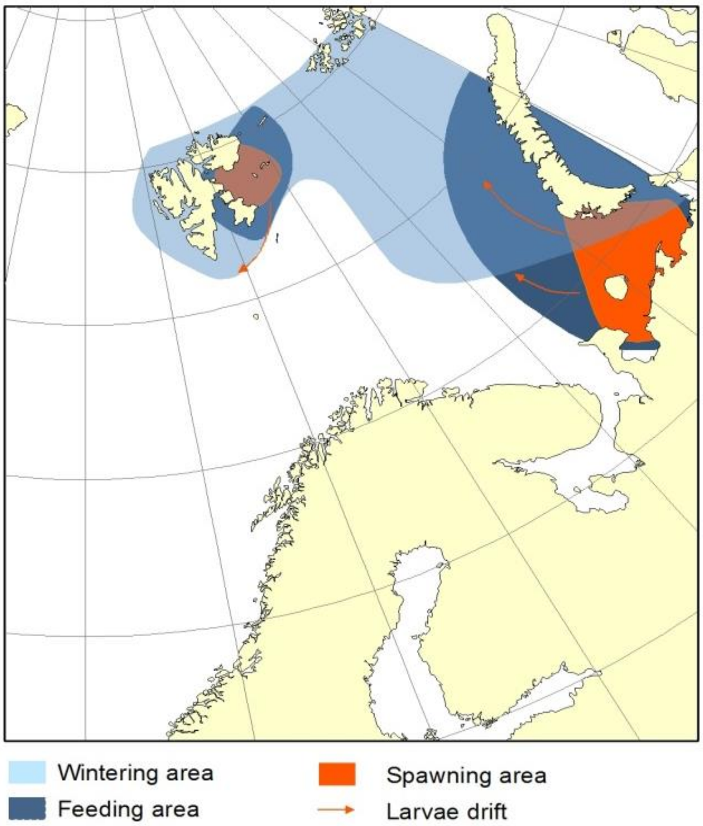


Figure 2.4.19. Distribution area for polar cod.

Figure 2.4.20. Distribution area for blue whiting.

Saithe *(Pollachius virens)*

Saithe is a boreal species found in north Atlantic waters (Figure 2.4.21). In the north-eastern Atlantic saithe is separated into six stocks: 1) west of Ireland; 2) west of Scotland; 3) around Iceland; 4) around the Faroe Islands; 5) in the North Sea; and 6) in the northeast Arctic — along the coast of Norway (62º N at Møre to Kola Peninsula) and the south-eastern Barents Sea. It also occurs at Svalbard in low abundance.

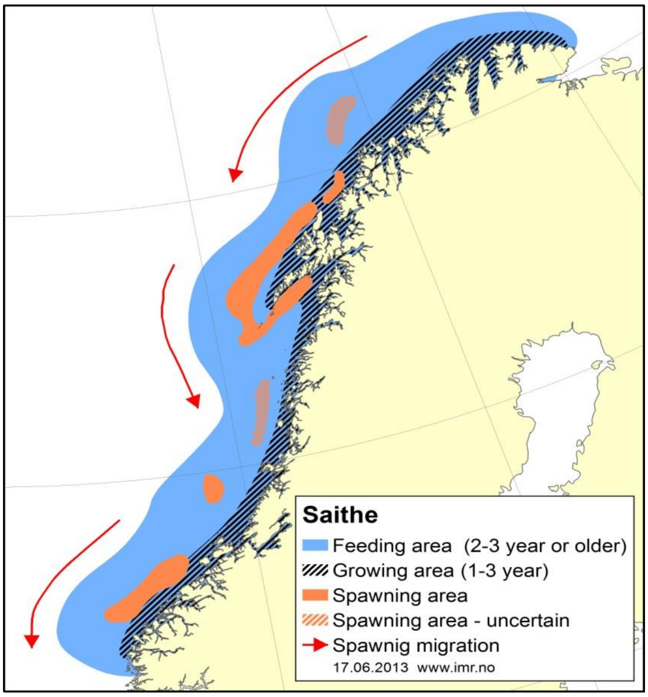


Figure 2.4.21. Distribution of saithe.

Tagging studies indicate that saithe undertake both feeding and spawning migrations; there are also migrations between stocks. Young saithe may migrate extensively from the western Norwegian coast to the North Sea. Adults follow Norwegian spring-spawning herring far out into the Norwegian Sea, sometimes all the way to Iceland and the Faroe Islands. Saithe occur in both pelagic and demersal zones of the water column, at depths from 0-300 m. They often occur in dense concentrations, e.g. in the pelagic zone where currents concentrate their prey items. Predominant prey items for young saithe are *Calanus* copepods, krill, and other crustaceans. With age they become increasingly piscivorous and prey on: herring; sprat; young haddock; Norway pout; and blue whiting. In the northeast Arctic saithe spawn during winter; peak spawning occurs during February at 150-200 m depths and temperatures from 6–10˚C. They undergo regular annual spawning migrations from the northern coast of Norway to areas off the western coast of Norway; they also sometimes migrate to northern regions of the North Sea, but to a lesser extent. Principal spawning areas are: Lofoten; Haltenbanken; and banks outside the Møre and Romsdal region. Eggs and larvae drift northward with the currents. Nursery grounds for 0 age-group saithe include shore areas extending from the western coast of Norway to south-eastern regions of the Barents Sea. They migrate to coastal banks as 2–4 year olds.

2.4.5.3 Other fishery species

Three wolffish species — common wolffish (*Anarhichas lupus*), spotted wolffish (*A. minor*), and northern wolffish (*A. denticulatus*) — occur in the Barents Sea and adjacent waters. Wolffish are large (up to 180 cm), long-lived (up to 25 years), and demersal. These life-history characteristics make them particularly vulnerable to exploitation. Common wolffish and spotted wolffish are fished commercially, while the fishery on northern wolffish is minimal.

Long rough dab (*Hippoglossoides platessoides*) are abundant and widely distributed in the Barents Sea. As one of the most common groundfish species, it plays an important role in the benthic community. Because it is hardly fished commercially, detailed information on its life history and ecology is limited, and physical processes which influence the dynamics of this species are not well understood. During 2004-2013, ecosystem survey swept-area measures of abundance for long rough dab have been between 300,000 and 600,000 metric tons (tonnes). This is likely a minimum estimate of stock abundance.

2.4.6 Marine mammals

K.M. Kovacs (NPI), A.K. Frie (IMR), M. Skern-Mauritzen (IMR), S.E. Belikov (VNIIPriroda), V.N. Svetochev (MMBI), and C. Lydersen (NPI)

Polar bears, seven pinniped species, and five cetacean species reside full-time in the Barents Sea Region. In addition, eight whale species are regular seasonal migrants that come into the Barents Sea to take advantage of summer-time peaks in productivity as the ice retreats northward during summer. Three additional dolphin species are observed occasionally in the southern Barents Sea; and sei whales (*Balaenoptera borealis*) have been observed north of

79° off the west coast of Spitsbergen; however, these species are considered rare north of the Norwegian Sea (Table 2.4.5).

The marine mammal community of the Barents Sea and adjacent northern waters represents a vast range of body sizes — from the ringed seal (1.3 m, 60 kg) up to the blue whale (24 m, 100,000+ kg) — and displays concomitant variation in life-history strategies and ecology (Kovacs et al., 2009). Most species feed at relatively high trophic levels, with polar bears and killer whales being apex predators. However, some of the largest baleen whales, such as blue whales and bowhead whales, feed at the zooplankton level of the food web, specialising on krill and copepods, respectively. The largest Barents Sea pinniped, the walrus also feeds primarily on small benthic invertebrates in shallow waters (e.g. Gjertz and Wiig, 1992). Other marine mammals in the region feed on a combination of benthic, pelagic, and even sympagic (ice-associated) fauna (including both fish and invertebrates). However, schooling fish including capelin, polar cod, and herring are the primary diet for many marine mammals in the Barents Sea Region (e.g. Nilssen et al., 1995; Bogstad et al., 2000; Andersen et al., 2004; Labansen et al., 2007). Climate change is having an impact on the Barents Sea fish community, resulting in a marked borealization of the region (Fossheim et al., 2015) that will have ramifications for the dietary composition of many marine mammal species in the coming decades. Declines in polar cod alone, will induce considerable change in the diets of many top trophic species (e.g. Haug et al., 2007; Labansen et al., 2007; Lindstrøm et al., 2013).

The large total biomass of marine mammals in the Barents Region implies that they play an important role in the structure and functioning of communities they occupy (Bowen, 1997). Consumption estimates for marine mammals in the Barents Sea suggest that, as a group, they consume 1.5 x the amount of fish biomass harvested by fisheries (e.g. Bogstad et al., 2000; Folkow et al., 2000; Nilssen et al., 2000). Examples of the impacts of extreme prey shortages — such as effects of the capelin stock crashes in the Barents Sea during the 1980s and 1990s — show that these top predators do experience "bottom-up" controls (Haug et al., 1991; Nilssen et al., 1998), and are clearly impacted by fishery overexploitation or environmental cycles which may cause reductions in stocks of their prey.

Currently, only minke whales and harp seals are commercially exploited by Norway, at low levels relative to their abundance. Ringed seals and bearded seals are harvested at low levels in both Russia and Norway. Quotas are set for commercial harvests, but for harp seals the take is only a small part of the allowable catch (ICES WGHARP, 2014). Additionally, a quota is set for harvesting white whales in the Russian Barents Region by the Fisheries Ministry (N=50 for the White Sea and N=200 for the Barents Sea); this species is protected in Norwegian waters. Coastal seals (harbour and grey seals) are legally harvested by licensed sport hunters in Norway and their numbers are also reduced by bounty hunts in some areas along the Norwegian coast (Nilssen and Haug, 2007; Nilssen et al., 2009); the coastal seals are protected in Russian waters. All other marine mammals are protected throughout the Barents Sea, both in Norwegian and Russian territories. Non-consumptive use of marine mammals in the Barents Region occurs primarily through tourism in the wild; this industry has increased rapidly in Svalbard over the past few decades and is also becoming more common within the Frans Josef Land Sanctuary. Small numbers of white whales are taken from the White Sea, from within the overall quota set by Russia, for display in aquariums and zoos around the world.

The abundance and diversity of marine mammals in the Barents Sea area attracted the attention of the earliest European explorers to the region. Massive harvesting which began in the 1600s targeted various marine mammal species over the next 300-400 years. All of the Great Whales were over-harvested, beginning with the earliest whaling that was concentrated on the fat, slow “right whale” family (including bowheads in the High Arctic). Advances in technology (such as the steam-driven engine, harpoon canons, effective floating mechanisms etc.) resulted in an expanded number of species that could be caught effectively. Walruses, seals, and polar bears were initially taken largely as by-catch in the northern whaling industry. But, these animals became the target of significant commercial harvesting in the Barents Sea and adjacent areas as whaling started to decline. Harbour seals, grey seals, and harbour porpoise have been exploited throughout their range by coastal inhabitants from early human history. Additionally, ringed seals, bearded seals, harp seals, and white whales have been harvested starting as early as the 1400s in Russian coastal areas of the Barents Sea (Alekseeva, 2008). West Ice harp seals and hooded seals have been the subject of commercial harvesting for centuries. However, due to precipitous declines in hooded seal populations following WWII, this species is now Red Listed by the International Union for the Conservation of Nature (IUCN); the West Ice quota (Norwegian and Russian hunting area) is set at zero (ICES WGHARP, 2008; Salberg et al., 2008). Analyses based on a 2012 survey, suggest that the Greenland Sea hooded seal population will likely continue to decline slowly even in the absence of commercial hunting (Øigård et al., 2014). Impacts of climate change are likely contributing to this trend; one factor being increased predation by polar bears on harp and hooded seal pups as the ice edge has moved closer to mainland Greenland in recent years (McKinney et al., 2013). Despite a history of over-exploitation, the Barents Sea region’s marine mammal community is still rich in species, and some populations, particularly among the pinnipeds, are very abundant (Table 2.4.5).

Table 2.4.5. Residency status and abundance of marine mammals in the Barents Sea region.

Common Name ***Genus species***	**Residency status**	**Abundance**	**Uncertainty* level**
Polar bear *Ursus maritimus*	Year-round	2650 (95% CI: 1900–3600)[1]	E
Walrus *Odobenus rosmarus*	Year-round	12000 (Sval. – 3886 - 95% CI: 3553-4262)[2a] Frans Josef Land thought to be similar to Svalbard (not surveyed) (Pechora Sea – 3943 – CI 3605-4325)[2b]	?
Ringed seal *Pusa hispida*	Year-round	100000 (Sval. partial - 7585 - 95% CI: 6332–9085)[3a] White Sea 20000[3b]	??
Bearded seal *Erignathus barbatus*	Year-round	Northern Barents Sea ~10,000 White Sea ~ 6000	??
Harp seal *Pagophilus groenlandicus*	Year-round**	1368200 (95% CO: 1226300-1509378, Barents Sea stock)[4a] 627410 (95% CI: 470540-786280, Greenland Sea stock)[4b]	E
Hooded seal *Cystophora cristata*	Year-round**	84020 (95% CI: 68060-99980)[4c]	E
Grey seal *Halichoerus grypus*	Year-round	2000 Troms-Finnmark[5] 3500 Murman coast[5]	E
Harbour seal *Phoca vitulina*	Year-round	3,500 (Sval. ~1800, CI range 1300-4418[6], Troms & Finmark 1967[7], 400-500 Murman Coast [8a], White Sea - unknown numbers[8b])	E/?
Bowhead whale *Balaenoptera acutorostra*	Year-round	Some hundreds[11]	??
White whale (beluga) *Delphinapterus leucas*	Year-round	10000	???
Narwhal *Monodon monoceros*	Year-round	1000	???
White-beaked dolphin *Lagenorhynchus albirostris*	Year-round	60000-70000[15]	??
Harbour porpoise *Phocoena phocoena*	Year-round	11000[16]	??
Blue whale *Balaenoptera musculus*	Seasonal migrant	NE Atlantic 979 (95% CI: 137-2542)9	E
Fin whale *Balaenoptera physalus*	Seasonal migrant	NE Atlantic 6409 (95% CI: 4356-9431)10 (c. 1,800 in Barents Sea proper and Spitsbergen Shelf)	E
Humpback whale *Megaptera novaeangliae*	Seasonal migrant	NE Atlantic 1450 (95% CI: 898-2341)10	E

Table 2.4.5 cont.

Common Name *Genus species*	**Residency status**	**Abundance**	**Uncer-tainty* level**
Minke whale *Balaenoptera acutorostrata*	Seasonal migrant	NE Atlantic 101615[12] Barents Sea (EB)34125[12] Norwegian Sea (EW) 21218[12]	E
Killer whale *Orcinus orca*	Seasonal migrant	NE Atlantic: - a few thousands[13]	???
Northern bottlenose whale *Hyperoodon ampullatus*	Seasonal migrant	A few sightings in the Norwegian Sea and west of Spitsbergen, no accurate estimate available (~60-70[14])	???
Long-finned pilot whale *Globicephala melas*	Seasonal migrant	A few sightings along the Norwegian coast, north to Bjørnøya, no estimate available	-
Sperm whale *Physeter macrocephalus*	Seasonal migrant	NE Atlantic 6,207 (95% CI: 4053-9505)[10]	E
Sei whale (*Balaenoptera borealis*)	Summer vagrant	-	-
Common dolphin *Delphinus delphis*	Summer vagrant	-	-
Bottlenose dolphin *Tursiops truncatus*	Summer vagrant	-	-
White-sided dolphin *Lagenorhynchus acutus*	Summer vagrant	-	-

*There is broad uncertainty in assessments of abundance for marine mammal population in the Barents Region: some populations have been assessed recently and completely (E); while many assessments are based on partial estimates by region that have been extrapolated to the whole Barents Sea (providing a reasonable or somewhat uncertain estimate); in some cases there is little or no available abundance data – so the values presented represent educated guesses based on sighting records or other less-quantitative estimators.

**harp and hooded seals leave the Barents Sea for breeding; some hooded seal populations undertake post-breeding or pre-molting foraging expeditions as well, while some spend much of the year in the Barents Region.

Sources: [1]Aars et al. (2009); a survey was flown in late summer 2015 and an updated estimate will be finalised in 2016, [2a]Kovacs et al. (2014), [2b] Lydersen et al. (2012a), [3a]Krafft et al. (2006), [3b]Lukin et al., (2006), new aerial surveys have been conducted, but the estimate is not yet revised; [4a]ICES WGHARP (2014), [4b]ICES WGHARP (2013), [5] Øigård et al. (2012), [6]Merkel et al. (2013), [7]Sjøpattedyrutvalget report (2014 unpubl. Data), [8a]Zyrvanov (2000), [8b] Vlad Svetochev, pers. comm. – but no recent data., [9]Pike et al. (2009), [10]Øien (2008), [11]Christensen et al. 1992a lists 10s to 100s – but recent sightings suggest that some few hundred in the region as a whole is likely; NPI unpublished data; [12] (NE Atlantic includes whole survey area minus Iceland) Solvang et al. (2015), [13]Foote et al. (2007), [14]Klepikovskiy and Shestopal (2006); [15]Øien 1993, [16] minimum estimate from Bjørge and Øien (1995).

2.4.7 Seabirds

H. Strøm (NPI), J.V. Krasnov (MMBI), S. Descamps (NPI), M.V. Gavrilo (AARI), P. Fauchald (NINA), G.H. Systad (NINA), and G. Tertitski (RAS)

Introduction

The Barents Sea Region supports some of the largest concentrations of seabirds in the world. A total of 33 species breed regularly in the region, and about 20-25 million seabirds harvest approximately 1.2 million tonnes of biomass annually from the area.

Seabirds spend most of the year at sea, visiting land only to breed, and find all their food in the marine environment (Schreiber and Burger, 2002). Typically, they form large breeding colonies in inaccessible locations along the coast or on remote islands. Seabirds are characterized by long life spans (10-40 years), deferred maturity (breeding delayed up to five years of age), small clutch size (only one egg in many cases), and extended chick rearing periods (sometimes up to several months) (Schreiber and Burger, 2002). Such life history characteristics imply that seabird populations are more vulnerable to factors which affect adult survival than factors which affect breeding success or survival to maturity (Gaston, 2004). Many seabirds are specialised top predators; therefore changes in their behaviour or population dynamics may reflect changes occurring at lower trophic levels or at early life stages. This makes them suitable indicators of changes occurring in the marine environment (e.g. Cairns, 1992; Furness and Camphuysen, 1997; Tasker and Furness, 2003).

A total of 33 seabird species breed regularly in the Barents Sea Region (Table 2.4.6, Figure 2.4.28). The majority belong to five systematic groups, including: *Gaviiformes* (divers); *Procellariiformes* (petrels and fulmars); *Pelicaniformes* (cormorants and gannets); *Anseriformes* (seaducks); and *Charadriiforms* (skuas, gulls, terns, phalaropes, and alcids).
Based on their foraging habitats (coastal vs. pelagic), their behaviour (surface feeding vs. diving) and principal diet (fish, zooplankton or benthos) seabird species can be divided into five ecological groups (Anker-Nilssen, 1994; Table 2.4.6). The pelagic feeding species dominate the Barents Sea seabird community, comprised both of diving — Brünnich's guillemot (*Uria lomvia*), Atlantic puffin (*Fratercula arctica*), and little auk (*Alle alle*) — and surface feeding species: northern fulmar (*Fulmarus glacialis*) and black-legged kittiwake (*Rissa tridactyla*).

Most seabird species breeding in the region are to some extent migratory, utilizing the high productivity during summer. More than 50% of the Barents Sea may be ice covered during winter. Although many populations leave the region during autumn and winter, they are often replaced by other populations from breeding areas further to the east which over-winter in the Barents Sea (e.g. Steller's eider/*Polysticta stelleri* and king eider/*Somateria spectabilis*, Figure 2.4.29).

Population sizes

The Barents Sea Region (here defined as the north-eastern part of the Norwegian and Greenland Seas, and the Barents and White Seas) supports some of the largest concentrations of seabirds in the world (Norderhaug et al., 1977; Anker-Nilssen et al., 2000). In total, more than 5 million pairs of seabirds breed in the region. The most abundant species are the: Brünnich's guillemot (*Uria lomvia/*1.25 mill. pairs); little auk (*Alle alle*/>1,000,000 pairs); Atlantic puffin (*Fratercula arctica*/910,000 pairs); and black-legged kittiwake (*Rissa tridactyla*/680,000 pairs). Other common species include: Northern fulmar (*Fulmarus glacialis/*500,000-1,000,000 pairs); common eider (*Somateria mollisima/*158,000 pairs); herring gull (*Larus argentatus/*122,000 pairs); common guillemots (*Uria aalge/*104,000 pairs); and Arctic tern (*Sterna paradisaea/*65,000 pairs). The Norwegian mainland, Novaya Zemlya, and Svalbard are the three main breeding areas; supporting more than 80% of the total breeding populations in the region (Table 2.4.6). However, precise estimates of the status of different seabird species in the Barents Sea region are made difficult by a lack of updated information from the eastern Barents Sea, especially Novaya Zemlya and Franz Josef Land.

High seabird density in the Barents Sea is a consequence of high primary production and large stocks of pelagic fish species such as capelin (*Mallotus villosus*), herring (*Clupea harengus*), and polar cod (*Boreogadus saida*). Seabird community composition reflects the environmental gradient from warm Atlantic areas in the south to cold ice-filled arctic areas in the North. In northern and eastern areas, the marginal ice-zone is important feeding habitat where seabirds forage on migrating capelin, polar cod, and zooplankton (Mehlum and Gabrielsen, 1993; Mehlum et al., 1996; Mehlum et al., 1998). Seabird communities in southern and western areas feed on juvenile gadoids, juvenile herring, sandeels (*Ammodytes sp*.) and capelin (e.g. Anker-Nilssen, 1992; Barrett and Krasnov, 1996; Barrett et al., 1997; Fauchald and Erikstad, 2002). Atlantic puffins, black-legged kittiwakes, and common guillemots dominate the seabird communities south of the Polar Front, while more Arctic species such as Brünnich's guillemot and little auk dominate in the north.

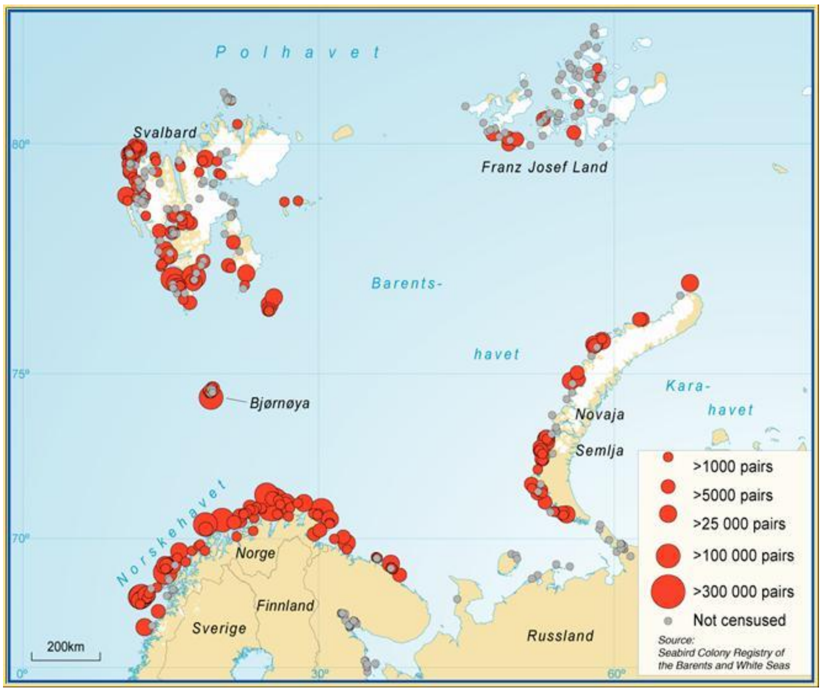


Figure 2.4.28. Seabird colonies in the Barents Sea Region. Source: The Seabird Colony Registry of the Barents and White Seas and NINA.

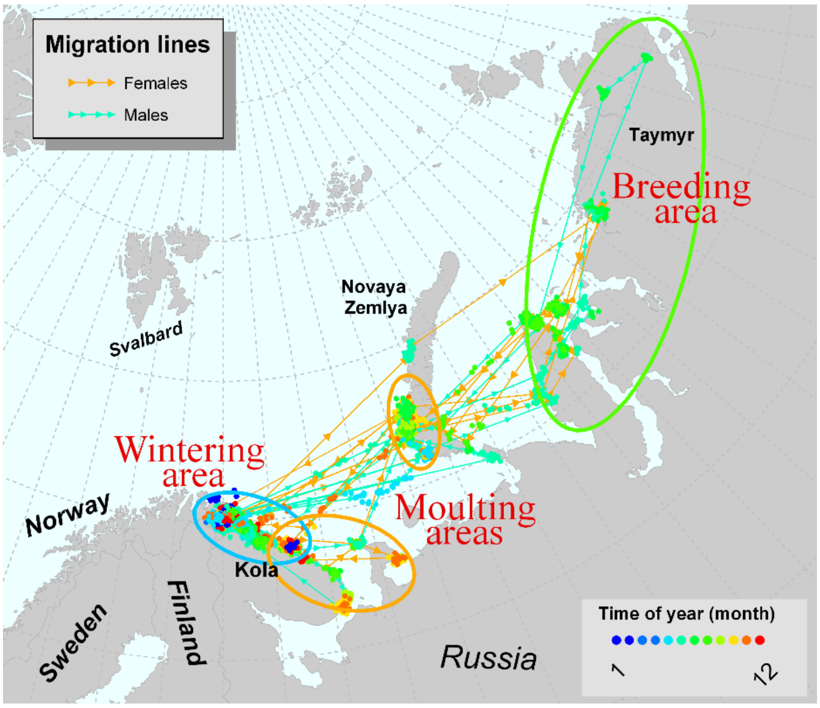


Figure 2.4.29. Steller's Eider migration patterns (Source: www.seapop.no).

Table 2.4.6. Breeding population estimates (pairs) of seabirds in the Barents Sea Region 2015.

			Regions							Total
Species		Ecological group	Norwegian coast	Murman coast	White Sea	Nenets district	Novaya Zemlya	Franz Josef Land	Svalbard	Pairs
Great northern diver	*Gavia immer*	CFi	0	0	0	0	0	0	0-3	0-3
Northern fulmar	*Fulmarus glacialis*	PSu	100	0	0	0	>2,500	7,000-8,000	500,000-1, 000,000	500,000-1,000,000
European storm-petrel	*Hydrobates pelagicus*	PSu	>100	0	0	0	0	0	0	>100
Leach's storm petrel	*Oceanodroma leucorhoa*	PSu	0	0	0	0	0	0	0	0
Northern gannet	*Morus bassanus*	PSu	2,100	150 -250	0	0	0	0	0	2,250-2,350
Great cormorant	*Phalacrocorax carbo*	CFi	5,500	1,200	370	0	0	0	0	7,070
European shag	*Phalacrocorax aristotelis*	CFi	5,000	350-400	0	0	0	0	0	5,350-5,400
Common eider	*Somateria mollisima*	CBe	9,000	3,000-4,000	9,500	1,500	25,000	1,000-2,000	17,000	66,000-68,000
King eider	*Somateria spectabilis*	CBe	0	0	0	500	?	0	500	1,000
Steller's eider	*Polysticta stelleri*	CBe	0	0	0	10 - 100	?	0	0	10-100
Long-tailed duck	*Clangula hyemalis*	CBe	?	?	?	?	?	0	<1,000	1,000
Black scoter	*Melanitta nigra*	CBe	?	?	?	?	?	0	0	?
Velvet scoter	*Melanitta fusca*	CBe	?	?	?	?	0	0	0	?
Red-breasted merganser	*Mergus serrator*	CFi	?	?	?	?	?	0	0	?
Arctic skua	*Stercorarius parasiticus*	PSu	?	?	150	?	?	?	>1,000	>1,150
Great skua	*Catharacta skua*	PSu	20	7-10	0	1 – 10	>50	0	1,000	1,100

Species		Ecological group	Regions							Total
			Norwegian coast	Murman coast	White Sea	Nenets district	Novaya Zemlya	Franz Josef Land	Svalbard	Pairs
Sabine's gull	*Xema sabini*	PSu	0	0	0	0	0	0	>10	>10
Mew gull	*Larus canus*	CSu	10,000	500	3,700	?	0	0	<5	14,200
Lesser Black-backed gull	*Larus fuscus*	PSu?	<100		>3200	0	0	0	<5	>3,300
Herring gull	*Larus argentatus*	CSu	11,500	17,500	5,100	0	0	0	<5	34,100
West-Siberian Gull	*Larus heuglini*	CSu	0	0	<100 (Tersky coast)	500-1,000	?	0	0	600-1,100
Glaucous gull	*Larus hyperboreus*	PSu	0	0	0	2000	> 2,000	>1000	4,000	>9,000
Great black-backed gull	*Larus marinus*	CSu	4,500	7,500	330	1	1	0	100	12,430
Black-legged kittiwake	*Rissa tridactyla*	PSu	37,000	< 87,000	40-50	150-200	40,000-50,000	100,000	245,000	515,000
Ivory gull	*Pagophila eburnean*	PSu	0	0	0	0	0	2,000-3,000	1,000-2,000	3,000-5,000
Common tern	*Sterna hirundo*	CSu	1,000	0	Few	0	0	0	0	>1,000
Arctic tern	*Sterna paradisaea*	CSu	4,000	<10,000	33,000	> 1,000	?	> 1,000	<10,000	59,000
Common guillemot	*Uria aalge*	PDi	14,000	7,800-8,400	0	0	750	0	132,000	155,000
Brünnich's guillemot	*Uria lomvia*	PDi	<100	1,800	0	0	250,000-500,000	200,000-250,000	615,000	1,067,000-1,367000
Razorbill	*Alca torda*	PDi	<45,000	100-1,000	3,870	0	1-10	0	120	19,600
Black guillemot	*Cepphus grille*	CBe	20,000	6,000	1,930	100	6,000-7,000	3,000-4,000	20,000	58,000
Little auk	*Alle alle*	PDi	0	0	0	0	30,000-	>500,000	>1,000,000	>1,530,000

Species		Ecological group	Regions: Norwegian coast	Murman coast	White Sea	Nenets district	Novaya Zemlya	Franz Josef Land	Svalbard	Total Pairs
							50,000			
Atlantic puffin	*Fratercula arctica*	PDi	907,000	<5,000	1-2	0	>100	0	<10,000	910,000

The most abundant species

Little auks and Brünnich's guillemot in combination are believed to be the most numerous seabird species in the Barents Sea Region. The largest colonies (several over 100,000 pairs) inhabit Spitsbergen, Hopen, Bjørnøya (Bear Island), and the west coast of Novaya Zemlya. Brünnich's guillemots generally winter in waters off Iceland, Greenland, and Newfoundland (Canada); although birds from Novaya Zemlya and Franz Josef Land likely remain in the Barents Sea throughout the year. Outside the breeding season Brünnich's guillemot appear in coastal waters and at sea, often in ice-filled areas. Their diet consists mainly of fish and crustaceans. In the northern Barents Sea, important prey items include polar cod and crustaceans.

For the Barents Sea little auk population, a crude estimate of more than one million pairs has been made, and the global population is set to more than 40 million pairs. Little auks feed in both inshore and offshore waters. Their main food during the breeding season consists of small crustaceans, especially copepods (*Calanus* spp.). At times other than the breeding season, the little auk is pelagic and migrates to wintering areas off south-western Greenland. Some little auks may also winter around Svalbard, in the Barents Sea, and along the Norwegian coast south to the Skagerrak.

Black-legged kittiwake is the most common gull in the Barents Sea region, and breeds in all sub-regions. It is also the most abundant species of gull in the world, and the most oceanic in its habitat. The total breeding population in the Barents Sea region is estimated to be 680,000 pairs. This species can be observed in all coastal areas as well as at sea, including ice-filled waters. The largest colonies are found on Bjørnøya, Hopen, and the west coast of Novaya Zemlya. The black-legged kittiwake feeds mainly on small fish up to 15-20 cm long and invertebrates, but they also scavenge offal or discarded fish behind fishing boats. In the northern Barents Sea, capelin, polar cod, amphipods, and euphausiids are important components of their diet. However, composition of their diet changes between areas and seasons. Kittiwakes disperse widely over most of the North Atlantic outside the breeding season.

The northern fulmar is restricted to north-western areas of the Barents Sea region, with a large breeding population in Svalbard. The northern fulmar is primarily a pelagic species which remains far out at sea except during the breeding season. Even during breeding, it sometimes makes long foraging trips. Fulmars breeding on Bjørnøya are known to feed in the central Barents Sea; during the chick-rearing period, they may along the coast of northern Norway (Weimerkirch et al., 2001). They feed on small pelagic animals caught near or on the sea surface; in Svalbard they feed mainly on squid, polychaetes, pteropods, crustaceans, and small fish. They also scavenge fishery discard and offal. In the Arctic, the fulmar has been observed in both open sea areas and in ice-filled waters.

In the Barents Sea region, the Atlantic puffin breeds primarily in northern Norway and western Murman coast; it also breeds in small scattered colonies in Novaya Zemlya, Spitsbergen, and Bjørnøya. During autumn, puffins assemble in the Barents Sea. Wintering areas for the different populations are poorly understood, but many birds winter in the southern Barents Sea and further south in the Norwegian Sea (Figure 2.4.30; www.seapop.no). Atlantic puffin feed mainly on small schooling fish. Crustaceans, squid, and polychaete worms are also important food items for some populations, especially outside the breeding season. Most puffins search for food in offshore pelagic waters. During the non-breeding season, they are pelagic in both distribution and feeding habits.

The common eider is the most abundant breeding sea duck inhabiting the entire coastline of the Barents Sea region. It is relatively sedentary and forms local populations. Common eiders breed on small islets where they are relatively safe from mammalian predators as long as there is no sea ice. They breed in colonies of variable size and density, but may also nest solitarily. Common eiders feed on various benthic animals; blue mussels *Mytilus edulis* are a preferred food source, which they catch by diving down to about ten metres. Small crustaceans, echinoderms, annelids, and small fish and their fry — found in the inter-tidal zone and the shallows — are also part of their diet. Common eiders in the High Arctic are migratory, and leave the breeding grounds, wintering along the coast of Kola and Northern Norway. Some birds from Spitsbergen winter in Iceland (Bakken et al., 2003). Some birds may spend the winter in restricted ice-free waters off the west coast of Svalbard, and possibly west off Novaya Zemlya. Mainland common eiders do not migrate far, and winter largely within their breeding range, leaving only the most easterly regions. In mid winter, abundance of common eiders in eastern Finnmark, Norway increases to approximately 50,000 individuals, indicating that birds from Russian populations move into this area (Figure 2.4.31). Also, there is an increase in the wintering population in western Finnmark from mid November, which corresponds to the size of the Svalbard population. King eiders exhibit a similar migration pattern.

Seabirds play an important role in transporting organic matter and nutrients from the sea to the land (Ellis, 2005). This transport is of great importance especially in the Arctic, where lack of nutrients is an important limiting factor. This is especially evident in the high-Arctic archipelagos of Svalbard and Franz Josef Land, where rich vegetation is found below seabird breeding colonies; this vegetation is then grazed by reindeer (*Rangiferus rangiferus*), geese (*Branta* spp. and *Anser brachyrhynchos*), and ptarmigan grouse (*Lagopus mutus*).

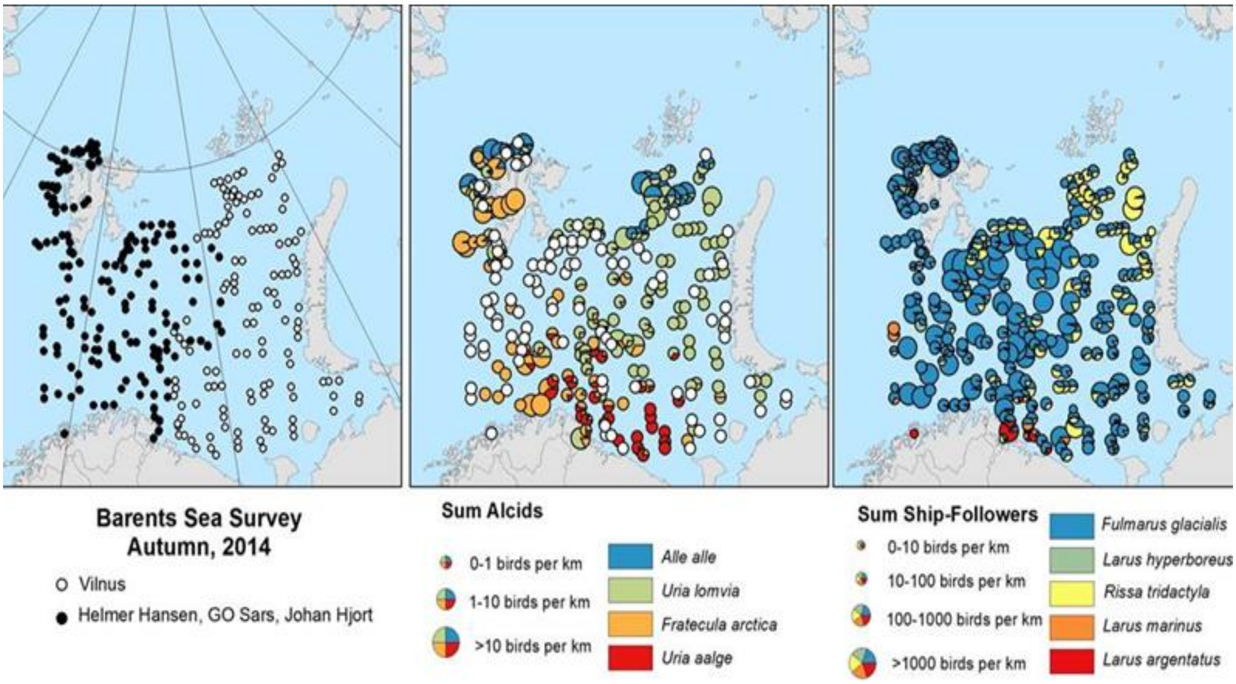


Figure 2.4.30. Seabird autumn distribution in open sea (Source: www.seapop.no).

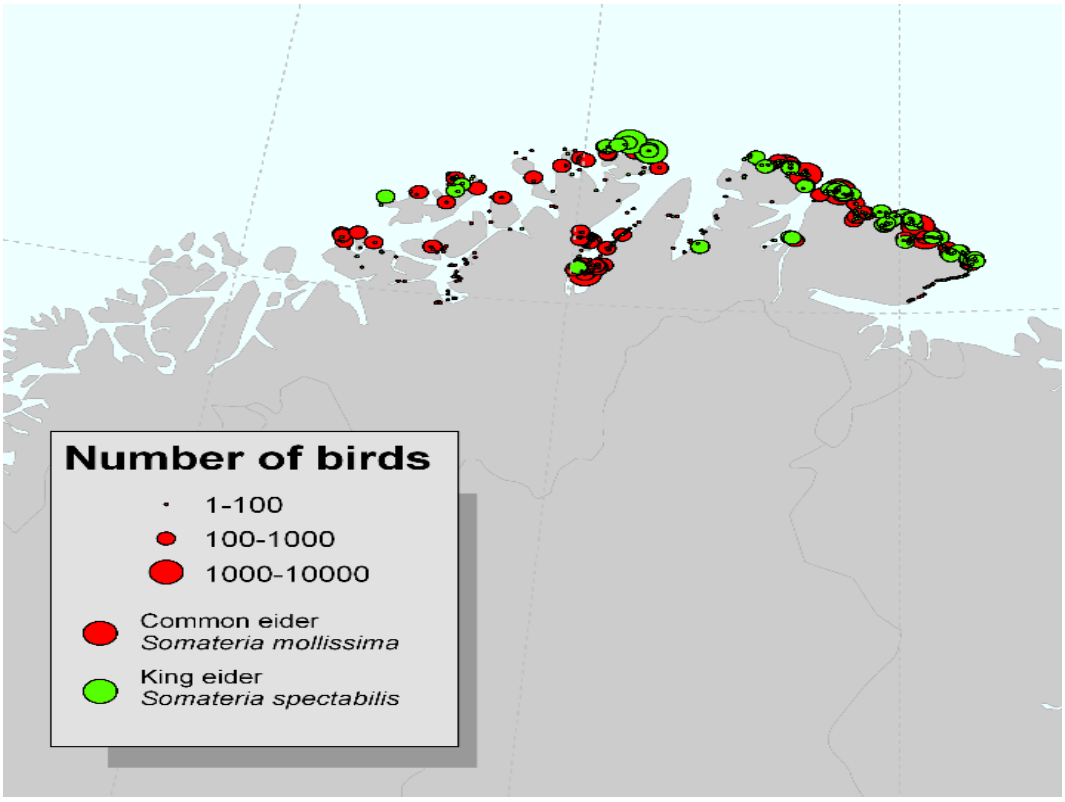


Figure 2.4.31. Common and King Eider distribution in Finnmark, March 1999 (Source: www.seapop.no).

2.4.8 Infectious organisms

V. Kuklin (MMBI), M. Tryland (UiT - Arctic University of Norway), and M.M. McBride (IMR)

2.4.8.1 Fish

At present, fish are considered best indicators of health of the aquatic environment, and of changes due to anthropogenic stressors. Frequency in the occurrence of disease is a valuable indicator of the state of the Barents Sea ecosystem, and can be useful to identify factors causing negative impacts. Monitoring long-term changes in the prevalence of diseases is needed to determine if, and how, they correlate with human activities and impacts (Karasev et al., 2011).

Data from 2006 indicate a low prevalence of fish disease in the Barents Sea. Mean prevalence for the period 1999-2007 is 0.6%. The highest proportion of diseased fish (2.0%) was observed in 2003. Between 2003 and 2011, only 02.-0.3% of fish sampled annually — including, cod, haddock, long rough dab, wolfish species, blue whiting, grenadier, saithe, and sculpins — were found to be diseased (Karasev et al., 2011).

As of yet, objective estimates of parasite species diversity for all organisms in the Barents Sea have not been possible because taxonomic groups of their hosts have been studied to varying degrees. However, parasites (mostly helminths) are an integral part of any marine ecosystem, and circulate in the sea through trophic relationships among nearly all living organisms in the foodweb. Karasev et al. (2011) reported 235 different species of parasites to occur in the Barents Sea, representing: 8 classes; 33 orders; 74 families; and 140 genera.

2.4.8.2 Helminthofaunal infections in seabirds

In surveys of 20 species of seabirds, 99 species of helminthes were recorded, 37 trematoda species, 41 cestoda species, 18 nematods, 5 species of the order *Acanthocephala*. There are 84 species of helminthes in birds from the Murman coast, and 49 of them are characteristic for that area only. There are 10 (1) species from Novaya Zemlja and 28 (7) from Svalbard. Six species of helminthes are found across the entire Barents Sea. Representatives of all main taxa of parasitic worms (trematoda, cestoda, nematoda, acanthocaphala) were found in 8 bird species: common eider (*Somateria mollissima*), Steller's eider (*Polystica stellery*), purple sandpiper (*Calidris maritime*), black-legged kittiwake (*Rissa tridactyla*), European herring gull (*Larus argentatus*), great black-backed gull (*L. Marinus*), glaucous gull (*L. Hyperboreus*), and black guillemot or tystie (*Cepphus grille*).

The helminth fauna of Barents Sea seabirds consists mostly of species with life cycles linked to coastal ecosystems. Invertebrates and fish from the littoral and upper sublittoral complex serve as their intermediate hosts. There are some exceptions to this: Cestodes from the *Tetrabothriidae* and *Dilepididae* families which are able to complete their entire life cycle in the open sea.

The highest levels of infection and highest diversity of parasites have been recorded in birds whose diet is based on littoral and upper sublittoral invertebrates. Ichtyophageous and planktophageous bird species have the lowest indices of infestation and parasite species diversity.

The diversity of trematode fauna in seabirds of the Arctic islands is quite poor; levels of infection are also quite low. This is due to a lack of intermediate hosts (mollusks) and unfavourable environmental conditions. At the same time many cestode species from the families *Dilepididae*, *Hymenolepididae, Tetrabothriidae*, and *Acanthocaphala* are found in birds from all parts of the Barents Sea. This is explained by the abundance of sublittoral crustaceans – intermediate hosts for those parasites (Kuklin and Kuklina, 2005).

Birds from the East Murman coast show strong local patterns in helminthofauna. To perform objective evaluation of parasitological situation, it is necessary to have data from areas that differ in their geographical and ecological parameters.

Over the past 50 years, there have been significant quantitative and qualitative changes in the avian helminthofauna of Murman, including changes in the composition of helminth species occurring, as well as a significant drop in levels of trematode and cestode infestation. This results from the decreased number of birds occurring and change in their food base. Capelin (*Mallotus villosus*) over-fishing has also played a significant role as it is a main food base for many species.

Pathogenicity of helminthes for the seabirds of the Barents Sea

Infestation of seabirds with helminthes leads to changes in levels of proteins, lipids, carbohydrate metabolism, and minerals. The presence of intestinal parasites causes changes in the physiological condition of blood as well as liver and kidney dysfunction. The most pronounced metabolic changes are recorded in birds infected with: cetodes from the *Hymenolepididae* and *Tetrabothriidae* families; cyclophyllid tapeworms from the *Dilepididae* and *Tetrabothriidae* families; trematodes from the *Microphallidae* family; and joint infections by trematodes from the *Microphallidae* and *Heterophyidae* families (Kuklin and Kuklina, 2005).Studies have shown that the most dramatic changes in metabolic processes of seabirds occur from the 4th through the 10th day after infestation, after which the system "parasite-host" becomes more stable and less antagonistic. Birds are most susceptible to infestation during the first year of life, probably due to an underdeveloped immune system.

2.4.8.3 Bacterial and viral infection in Marine mammals

Bacteria of the genus *Brucella* are widely distributed among marine mammals in the Barents Sea, including in the polar bear population (Nymo et al., 2011). A previous investigation revealed high prevalence of anti-*Brucella* antibodies (35%) and *Brucella*-bacteria (*Brucella pinnipedialis*; 38%) in hooded seals (*Cystophora cristata*). Such antibodies were also detected in: harp seals (*Phoca groenlandica*); ringed seals (*Pusa hispida*); minke whales (*Balaenoptera acutorostrata*); fin whales (*B. physalus*); and sei whales (*B. borealis*) (Tryland et al., 1999). *Brucella pinnipedialis* was isolated from 38 % of the investigated hooded seals (n=29) from the north-east Atlantic Ocean, but not from ringed seals (*Pusa hispida*) from Svalbard; no pathological lesions were associated with the presence of bacteria (Tryland et al., 2005b). A *Brucella* sp. isolate was also obtained from a minke whale off the coast of Finnmark, Northern Norway (Clavareau et al., 1998). A recent study revealed that pups (< 1 month old) had a substantially lower seroprevalence (2.5 %) than yearlings (35 %), suggesting that the bacterium is not transferred from mother to pup, and that the animals are exposed during their first year of life (Nymo et al., 2013). Recent studies have also indicated that isolates of *Brucella pinnipedialis* obtained from hooded seals have a less pathogenic character than many other species of *Brucella* bacteria (Larsen et al., 2013; Nymo et al., 2014). Anti-*Brucella* antibodies have also been detected in polar bears from Svalbard (3.6 %, n=253) and the Barents Sea (15.9 %, n=44) (Tryland et al., 2001).

The bacterium (*Bordetella bronchiseptica*) has been identified as a frequent secondary invader and pathogen in seals, following infections with phocine distemper virus (PDV) (Register et al., 2000). Also *Salmonella* sp., *Mycobacterium* sp. and *Mycoplasma* sp. may cause disease in marine mammals and are also zoonoses, i.e. can cause infectious disease in man (Tryland, 2000; Tryland et al., 2014).

Phocid Herpesvirus Type 1 (PhHV-1) cause infections with clinical signs of upper respiratory tract disease, fever, vomiting, diarrhea, acute pneumonia and hepatitis in neonatal phocids, and can also cause ocular infections (wild and captive seals). Antibodies against PhHV-1 have been detected in harp seals (*Phoca groenlandica*) and hooded seals (*Cystophora cristata*) of the North-East Atlantic Ocean (Stuen et al., 1994). In harbor seals at Svalbard, antibodies (72-100%, n= 383, 1998-2010) and PhHV-1-specific DNA in ocular swab samples (8 %, n= 73, 2009; 3 %, n= 63, 2010) have been detected, but no clinical symptoms associated with the PhHV-1 infections were found (Roth et al., 2013).

Phocine distemper virus (PDV) usually gives respiratory disease in seals, but also symptoms from CNS. PDV epizootics killed approximately 18,000 and 22,000 harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) along the coasts of northern Europe in 1988 and 2002, respectively (Seibel et al., 2007; Duignan et al., 2014). No such disease has been seen in coastal seal colonies in northern Norway or Svalbard, but antibodies have been detected in harbour seals and walrus (*Odobenus rosmarus*) at Svalbard (5% and 31%, respectively) (M. Tryland, unpublished data). Antibodies against PDV were also detected in harp seals (*Phoca groenlandica*) and hooded seals (*Cystophora cristata*) from the pack ice of the Greenland Sea, north of Jan Mayen (West Ice) (Stuen et al., 1994), and in polar bears (*Ursus maritimus*) from Svalbard and the Barents Sea (8%) (Tryland et al., 2005a).

Infection with rabies virus was observed in one ringed seal at Svalbard in 1980. Influenza-virus, parapoxvirus, and calicivirus may also cause disease in marine mammals, and also are potential zoonotic agents (Tryland et al., 2014). When testing polar bears for calicivirus, an antibody prevalence of 2 % was found, whereas no individuals had antibodies against rabies virus (Tryland et al., 2005a).

2.4.9 Rare and threatened species

M. Tsyganova (VNIIPriroda), M. Gavrilo (AARI), I. Salvesen (ADB), S.E. Belikov (VNIIPriroda), J. Gjøsæter (IMR), J.A. Kålås (ADB), and H. Strøm (NPI)

In this chapter we handle species of particular conservation concern due to their population status. These are the species present in the Barents Sea area and also listed on the Global Red List (IUCN, 2015), the Russian Red Data book (Danilov-Danilyan et al., 2001)* and/or the Norwegian Red List (Kålås et al., 2006). The groups of species included are restricted to mammals, birds and fish species. This is due to the general lack of knowledge and lack of relevant assessments for other taxonomic groups in the Barents Sea area. Some information is available in the Norwegian 2006 Red List, but both the Global Red List and the Russian Red Data Book include such assessments to a minor degree. For future reports the goal should be to include a far broader spectrum of taxonomic groups.

Species included in this chapter have either very small populations or have recently undergone considerable population decline (or are expected to do so in the near future). Assessments are conducted using the IUCN criteria (IUCN, 2015); however the 3 lists (Global, Russian, and Norwegian) cannot be compared directly. The Global list is based on the global assessment (IUCN, 2015), and includes assessments for the global population of particular species. The Norwegian Red List is a regional red list using the IUCN categories and criteria on a Norwegian scale (IUCN, 2015), i.e. covering Norwegian populations and 'rescuing' effects from neighbouring populations. The framework for the Red Data Book of the Russian Federation is based on: the Federal law “On the Environmental Protection" (10 January, 2002); the Federal law "About animal world" (5 May, 1995); and the Decree of the Government of the Russian Federation #158 (February 19, 1996) — which states the Red Data Book of the Russian Federation to be an official document providing information about rare and endangered species of animals and plants, as well as necessary measures for their protection and recovery. In other words, it represents a state inventory of such species as well as scientific background for their conservation strategies in Russia. All these lists are closely related and have high relevance for the conservation of biodiversity.

Relevant species are presented in Table 2.4.7 that, in addition to the Red List categories, gives information about the species status relative to international conventions or agreements. However, all conventions/agreements are not relevant for all species groups.

This table includes a total of 56 species, comprised of 28 fish species, 9 bird species, and 16 mammal species. More detailed information on particular species of fish, birds, and mammals is included in other chapters of this report.

Table 2.4.7. Threatened species in the Barents Sea.

Convention/International Agreement	Status Explanation
IUCN Red List Categories and Criteria: Version 3.1. 2001. Norwegian Red List	**EX –** extinct; **EW -** Extinct in the Wild; **CR -** Critically Endangered; **EN**- Endangered; **VU –** Vulnerable; **NT** - Near Threatened; **LC-** Least Concern; **DD -** Data Deficient; **NE -** Not Evaluated
The Red Data Book of the Russian Federation	**0**- Probably extinct; **1**- Endangered; **2** - Decreasing number; **3**- Rare; **4** - Uncertain status; **5** - Rehabilitated and rehabilitating
Convention on the Conservation of European Wildlife and Natural Habitats Bern, 19.IX.1979 (The Bern Convention)	**2** – species listed in Annex II to the Convention; **3** – species listed in Annex III to the Convention
Convention on the Conservation of Migratory Species of Wild Animals (CMS) (The Bonn Convention), updated 2008	**1** – species listed in Annex I to the Convention; **2** – species listed in Annex II to the Convention
OSPAR List of Threatened and declining species OSPAR Commission, 2008	**X** - Bird species included in OSPAR List of Threatened and/or Declining Species and Habitats
SPEC Category and Threat Status. Birds in Europe Series: Population Estimates, Trends and Conservation Status BirdLife International. 2004	**SPEC 1** – Species of global conservation concern, i.e. classified as globally threatened, Near Threatened, or Data Deficient; **SPEC 2** – Concentrated in Europe and with an Unfavourable Conservation Status; **SPEC 3** – Not concentrated in Europe but with an Unfavourable Conservation Status; .**Non-SPECE** – Concentrated in Europe but with a Favourable Conservation Status; **Non-SPEC** – Not concentrated in Europe and with a Favourable Conservation Status.

	Status							
	UICN Red List Cat/Crit	**The Red Data Book of the Russian Federation**	**UICN Red List Cat/Crit**	**International Conservation instruments**				
Species				**CITES**	**The Bern Convention**	**The Bonn Convention**	**OSPAR List of Threatened and declining species**	**SPEC category & Threat Status**
1	2	3	4	5	6	7	8	9
Birds								
Gavia adamsii		3	NT (Winter)		2	2	-	NON-SPEC, S (P)
Phalacrocorax carbo		Bio			3	-	-	NON-SPEC, S
Phalacrocorax aristotelis		3			2	-	-	4, S
Somateria mollisima		Bio			3	2	-	NON-SPEC, S
Polysticta stelleri	VU/A2bcd+3bcd+4bcd	Bio	VU/C1 (Winter)		2	1	+	1, L*W
Xema		Bio			2	-	-	NON-SPEC, S

Table 2.4.7 cont.

Species	Status							
	UICN Red List Cat/Crit	The Red Data Book of the Russian Federation	UICN Red List Cat/Crit	International Conservation instruments				
				CITES	The Bern Convention	The Bonn Convention	OSPAR List of Threatened and declining species	SPEC category & Threat Status
1	2	3	4	5	6	7	8	9
Birds cont.								
Rissa tridactyla		No	VU/A2b		3	2	+	NON-SPEC,S
Pagophila eburnean	NT	3	EN/C1 (Svalbard)		2	-	+	3, E(P)
Uria aalge		No	CR/A2ab		3	2	-	NON-SPEC, S
Fratercula arctica		No	VU/A2b		3	2	-	2, 4
Mammals								
Ursus maritimus	VU/A3c	4	Svalbard VU/A3c		2			
Odobenus rosmarus	DD	2	Svalbard VU/D1		2			
Phoca vitulina		3	VU/A3b (Svalbard D1)		3	2		
Halichoerus grypus		3	NT		3	2		
Lagenorhynchus acutus		4		2	2	2		
Lagenorhynchus albirostris		3		2	2	2		
Phocoena phocoena	VU/A2b	4		2	2			
Cystophora cristata	VU/A2b		VU/A2a					
Monodon monoceros	NT	3	DD	2	2	2		
Hyperoodon ampullatus	DD	1		1	3	2		
Balaena mysticetus		1	CR/D1	1	2	1		
Megaptera novaeangliae		1		1	2	1		
Balaenoptera musculus	EN/A1abd	1	NT	1	2	1		
Balaenoptera physalus	EN/A1d	2		1	2			
Delphinapterus leucas	NT		DD					

Table 2.4.7 cont.

Species	Status							
	UICN Red List Cat/Crit	The Red Data Book of the Russian Federation	UICN Red List Cat/Crit	International Conservation instruments				
				CITES	The Bern Convention	The Bonn Convention	OSPAR List of Threatened and declining species	SPEC category & Threat Status
1	2	3	4	5	6	7	8	9
Mammals cont.								
Eubalaena glacialis	EN/D1	1	RE			Eubalaena glacialis	EN/D1	1
Lutra lutra	NT		VU/Ab4			Lutra lutra	NT	
Fish								
Anguilla anguilla			CR/A3bd	App II			X	
Squalus acanthias	VU/A2bd+3bd+4bd		CR/A2d				X	
mmodytes marinus			VU/A2abcd					
Lamna nasus	VU/A2bd+3d+4bd		VU/A2ad				X	
Molva dypterygia			VU/A1d					
Sebastes marinus			VU/A4b					
Sebastes mentella			VU/A3b					
Hippoglossus hippoglossus	EN/A1d		NT					
Molva molva			NT					
Somniosus microcephalus	NT		NT					
Theragra finnmarchica			NT					
Trisopterus esmarkii			NT					
Amblyraja hyperborea			DD					
Bathyraja spinicauda	NT		DD					
Careproctus derjugini			DD					
Careproctus dubius			DD					

Table 2.4.7 cont.

Species	Status							
				International Conservation instruments				
	UICN Red List Cat/Crit	The Red Data Book of the Russian Federation	UICN Red List Cat/Crit	CITES	The Bern Convention	The Bonn Convention	OSPAR List of Threatened and declining species	SPEC category & Threat Status
1	2	3	4	5	6	7	8	9
Fish cont.								
Careproctus knipowitschi			DD					
Careproctus tapirus			DD					
Careproctus telescopus			DD					
Cottunculus konstantinovi			DD					
Cyclopteropsis mcalpini			DD					
Gymnelus andersoni			DD					
Gymnelus viridis			DD					
Leucoraja fullonica			DD					
Liparis tunicatus			DD					
Gadus morhua	VU/A1bd						North Sea	
Melanogrammus aeglefinus	VU/A1d+ 2d							
Chimera monstrosa	NT							

2.4.10 Introduced species

M. Tsyganova (VNIIPriroda), B. Berenboim (PINRO), I. Salvesen (ADB), J. Gjøsæter (IMR), A. Jelmert (IMR), and J.A. Kålås (ADB)

Invasion of non-indigenous species — spread of the representatives of various groups of living organisms beyond their primary habitats — is global in nature. Non-indigenous species often act as biological pollutants, and may threaten the ecological security of a region. Their introduction and further spread often leads to the undesirable environmental, economic, and social consequences.

- Bioinvasion includes all cases of introduction of living organisms into ecosystems outsides of their original (usually natural) range. This may occur through various pathways, including:
- Natural movement associated with population dynamics and climatic changes;
- Intentional introduction and reintroduction;
- Nonintentional introduction after being transported in the ballast waters of ships.

During the last half century, 2 major crab species were introduced to the Barents Sea: red king crab (*Paralithodes camtschaticus*) in the 1960s; and snow crab (*Chionoecetes opilio*) in the 1990s.

In the beginning of this century, the following non-indigenous fish species expanded their habitat range from the southern boreal complexes northward into the Barents Sea: snake pipefish (*Eutelurus aequoreus*); sail ray *(Dipturus linteus);* whiting (*Merlangus merlangus*); grey gurnard (*Eutrigla gurnardus*); and megrim (*Lepidorhombus whiffiagonis*). These fish species can only occur in the Arctic waters of the Barents Sea during periods of anomalous climate warming, and thus may considered temporary residents.

Four species of nudibranch snails have recently been for the first time on the Murman coast of Russia; these gastropods are likely to have migrated eastward in response to a warming Arctic Ocean (Martynov et al., 2006). Also, established populations of the sea snail (*Aporrhais pespelecani* sp) have recently been observed on the Murman coast of the Barents Sea — signifying that this mollusc has expanded its range nearly 1,000 km eastward.

Also during this century (2000), fish species from southern boreal areas have expanded northward to appear in the Barents Sea, including the: snake pipefish (*Entelurus aequoreus*); snail ray (*Dipturus linteus*); whiting (*Merlangius merlangus*); grey gurnard (*Eutrigla gurnardus*); and megrim (*Lepidorhombus whiffiagonis*). Both crab species appear to have become permanent residents. These fish species, however, have occurred in the Barents Sea only during anomalously warm periods and, thus, may be regarded as temporary residents (Berenboim and Sundet, 2011).

Nonetheless, a number of nonindigenous species — which were either deliberately or accidentally introduced to the Barents Sea as a result of human activity — will probably stay in the Barents Sea for an indefinite period of time.

Under various predicted scenarios for climate change in the Arctic, warming periods may last quite some time. Hence, there is need to explore possible range expansions of other boreal species, and their impacts on indigenous communities. It also is important to evaluate the long-term economic consequences (positive and negative) of introduced species.

Table 2.4.8. Introduced species.

Name	Main taxon (phylum/class/order)
Species that appeared in the Barents Sea as a result of human activity:	
Codium fragile ssp scandinavicum (*)	Chlorophyta /Bryopsidophyceae/Bryopsidales
Bonnemaisonia hamifera	Rhodophyta/Florideaphyceae/Bonnemaisoniales
Caprella mutica	Arthopoda/Malacostraca/Amphipoda
Paraltihodes camtsachaticus	Arthropoda/Malacostraca/Decapoda
Cionocetes opilio	Arthropoda/Malacostraca/Decapoda
Species that are in the Norwegian Sea, approaching the Barents Sea:	
Heterosiphonia japonica	Rhodophyta/Florideaphyceae/Ceramiales
Molgula manhattensis	Chordata/Ascidacea/Pleurogona
Balanus improvisus	Arthopoda/Maxillopoda/Sessilia
Species not encountered in Norway, but with the possible high environmental impact	
Didemnum vexillum	Chordata/Ascidacea/Enterogona
Uncertain transportation/distribution (cryptogenic species):	
Gyrodactylus salaries	Plathyhelminthes/Trematoda/Monopisthocotylea

2.4.10.1 Red king crab (*Paralithodes camtschaticus*)

This species was deliberately introduced from the Far East to the Kola Bay and the adjacent waters of the Barents Sea by Russian scientists to enhance the fishing resources, in the 1960s. During the 1980s and 1990s they expanded to new areas and the crab reached the Norwegian shelf, and occupied practically all large fjords in the eastern Finnmark. Therefore, in the early 1990s, the crab caused heavy problems for the traditional fisheries. In addition, anxiety was expressed that this new species could cause serious harm to the biodiversity of the marine ecosystem. On the other hand, the red king crab was considered as a valuable fishing resource for the fishing industry in both countries. Therefore, a joint red king crab research was regularly discussed at the Joint Norwegian-Russian Fisheries Commission (JNRFC).

2.4.10.2 Snow crab (*Chionoecetes opilio*)

This species has not been deliberately introduced into the Barents Sea and is therefore considered to be an auto-invasive species. There are several hypotheses on how it was introduced and we think there are two probable ways. It may have migrated from the Beaufort Sea north through the Siberian Sea since it has been recorded in most areas along this track including the Kara Sea. Today distribution pattern in the eastern Barents Sea supports such a hypothesis. There is however, also a possibility that the snow crab larvae could be brought to the Barents Sea through ballast water from the crabs' native areas.

2.5 Human activities

The Barents Sea is strongly influenced by human activities; historically, related to fisheries and hunting marine mammals. More recent human activities also involve: ship transport of goods; oil and gas activities (exploration, extraction, and shipping); tourism; aquaculture; and bioprospecting. In recent years, interest has increased to determine the most likely response of the Barents Sea ecosystem due to anthropogenic effects and future climate change.

2.5.1 Fisheries and other harvesting

Harvested demersal stocks in the Barents Sea and adjacent waters (ICES areas I and II) include cod, haddock, saithe, and shrimp. In addition, redfish, Greenland halibut, anglerfish, wolffish, and flatfish species (e.g. long rough dab and plaice) are common on the shelf and at the continental slope. Ling and tusk are common at the slope and in deeper waters. In 2012, catches of about 1,300 thousand tonnes are reported from stocks of cod, haddock, saithe, redfish, Greenland halibut, and anglerfish.

The main pelagic stock harvested in the Barents Sea is capelin, but polar cod is also harvested. During 2009-2013, capelin supported a combined fishing quota of 200,000-400,000 tonnes. During 2014, the quota was reduced to 65,000 tonnes. There was no fishery for polar cod in 2012-2013 due to low interest from the industry. Young herring is found in the Barents Sea, but is not fished there. Herring is fished in adjacent waters — the Norwegian Sea and along the Norwegian coast — mainly in ICES area IIa, but there are also some catches in ICES area IIb and areas further west. Both the herring stock and its fishery appear to be in decline; the total quota was decreased from 619,000 tonnes in 2013 to 419,000 tonnes in 2014. The highly migratory blue whiting and mackerel stocks have extended their feeding migrations into the Barents Sea, and in 2013 about 26,000 tonnes of blue whiting and 211,000 tonnes of mackerel were harvested in ICES areas IIa and IIb.

Species with relatively low landings from the Barents Sea include: salmon *Salmo salar*; Atlantic halibut (*Hippoglossus hippoglossus*); European hake (*Merluccius merluccius*); pollack (*Pollachius pollachius*); whiting (*Merlangius merlangus*); Norway pout (*Trisopterus *esmarkii*); anglerfish (*Lophius piscatorius*); lumpsucker (*Cyclopterus lumpus*); and types of argentines, grenadiers, flatfishes, dogfishes, skates, crustaceans, and molluscs.

The most widespread gear used in the central Barents Sea is bottom trawl; in demersal fisheries longlines and gillnets are also used. Pelagic fisheries use purse seines and pelagic trawls. Other gears commonly used along the coast include handlines and Danish seines. Less frequently used gears include float-lines (used in a small directed fishery for haddock along the coast of Finnmark, Norway) and various pots and traps (used to catch fish and crabs). Gears used vary with fishing season, area, and country; Norway has the largest variety due to the coastal fishery. In Russian fisheries, bottom trawls are the most commonly used gear type. A longline fishery — mainly directed at cod and wolffish — is also conducted; although this fishery has increased in recent years, it remains at a relatively low level. Other countries fishing in the Barents Sea mainly use bottom trawls.

For most of the exploited stocks a catch quota (TAC) is agreed upon, and a number of additional regulations are applied. Regulations differ between gear types and species, and may differ between countries.

From 2011 onwards, the minimum mesh size for cod and haddock bottom trawl fisheries has been 130 mm for the entire Barents Sea; previously, the minimum mesh size was 135 mm in the Norwegian EEZ and 125 mm in the Russian EEZ. It is still mandatory to use sorting grids. A compromise agreement between Norway and Russia has been in effect since 2011 on the minimum legal retention length for cod: from 47 cm (Norway) and 42 cm (Russia) to 44 cm for both countries. Likewise for haddock: from 44 cm (Norway) and 39 cm (Russia) to 40 cm for both. This change may lead to increased fishing opportunities in areas which previously would be closed; it may also lead to increased discarding of undersized fish, when larger fish are available. Accordingly, effects of these regulatory changes should be carefully monitored.

2.5.2 Oil and gas activities

O. Korneev (SMG), O. Raustein (NPD), A. Ovsyannikov (SMG), and O.W. Lind (NPD)

2.5.2.1 Historical development

Russia

Seismic surveys in the Russian sector of the Barents Sea began in late 1960s. The process consisted of 5 stages:

1. Until 1973, the first reconnaissance transsections were done in the southern part of Pechora sea shelf;
2. During 1972 -1978, “SEVMORGEOLOGIA” conducted research on the entire southern Side of the Barents Sea shelf, including Yuzhno-Barents (southern Barents) depression;
3. During 1978-1990s, a number of large and unique deposits of oil, gas and gas condensate were located, primarily in the southern and central parts of the Barents Sea;

4. During 1979-1980, three specialised organisations were established in Murmansk — Arktikmorneftegazrazvedka (AMNGR) for exploratory drilling and oil production; Sevmorneftegeofizika (SMNG) for seismic research; and Arctic Marine Engineering-Geological expedition (AMIGE) for complex geotechnical investigations;
5. Starting in 1995, focus was placed on northern parts of the Barents Sea shelf. The regional stages of exploration were completed during 2008-2014, during this period seismic surveys were conducted by the operators; Gazprom and Rosneft in licenced areas.

During 2014, 2D-seismic surveys were carried out over 17,315 square km, and 3D-seismic surveys were carried out over 5,797 square km, within licensed areas in the Russian sector of Barents Sea. Based on the seismic survey data collected (state and private), "VNIIOkeangeologia" estimated 486,290 linear km in the Russian sector of the Barents Sea, which provided the regional (low) network density equal to 0.46 / km^2 (Figure 2.5.10). As a result of these surveys and the drilling of 55 exploration wells by state and private companies, 11 field deposits were discovered in the Barents and Pechora seas, including: 4 oil deposits (Prirazlomnoe, Varandey-sea, sea-Medyn, Dolginskoye); 1 oil and gas deposit (North Gulyaevskaya); 3 condensate deposits (Pomerania, Ice, Shtokman); and 3 gas deposits (North Kilda, Murmansk, Ludlovskoe).

Norway

Seismic data acquisition on the Norwegian shelf is divided into several categories: seismic surveys performed by the authorities; commercial seismic; and scientific data gathering. Since 1969, the Norwegian authorities have acquired seismic data in unopened areas of the Norwegian Sea and in the Barents Sea. Seismic surveys have also been conducted in the area around Svalbard. Until 2001, purchase of Norwegian Petroleum Directorate's seismic data for the southern Barents Sea was mandatory for companies wishing to acquire other data in the same area. This requirement has been discontinued in accordance with Storting White Paper No. 39 (1999-2000).

During the period 2007-2009, the Norwegian Petroleum Directorate performed regional 2D and 3D seismic surveys in the Nordland VII area and a limited area in Troms II, as a follow up to the integrated management plan. After an agreement between Russia and Norway in 2011 regarding boundary delimitation of neighbouring area in the Barents Sea, the Norwegian Petroleum Directorate performed between 2011-2012 regional 2D seismic surveys in the Barents Sea South-East area. This area was opened for petroleum activity in 2013, and selected blocks are included in the planned 23rd licensing round for petroleum exploration on the Norwegian continental shelf. Based on a recommendation from the Government, a group of 33 oil companies was established with Statoil as operator. In 2014, 3D seismic data was acquired, covering the selected blocks in the Barents Sea South-East area (Figure 2.5.10).
Further differentiation has been made between company-owned seismic, license-owned seismic, and marketable seismic. All these categories have in common that an exploration permit must be obtained from the Norwegian Petroleum Directorate. These data are being reported to the authorities in accordance with provisions in Section 10.4 of the Petroleum Act.

The authorities have also issued scientific exploration licences. These licences grant the owner exclusive rights to publish the results.

A common map of seismic surveys in both parts of Barents Sea is represented in Figure 2.5.1.

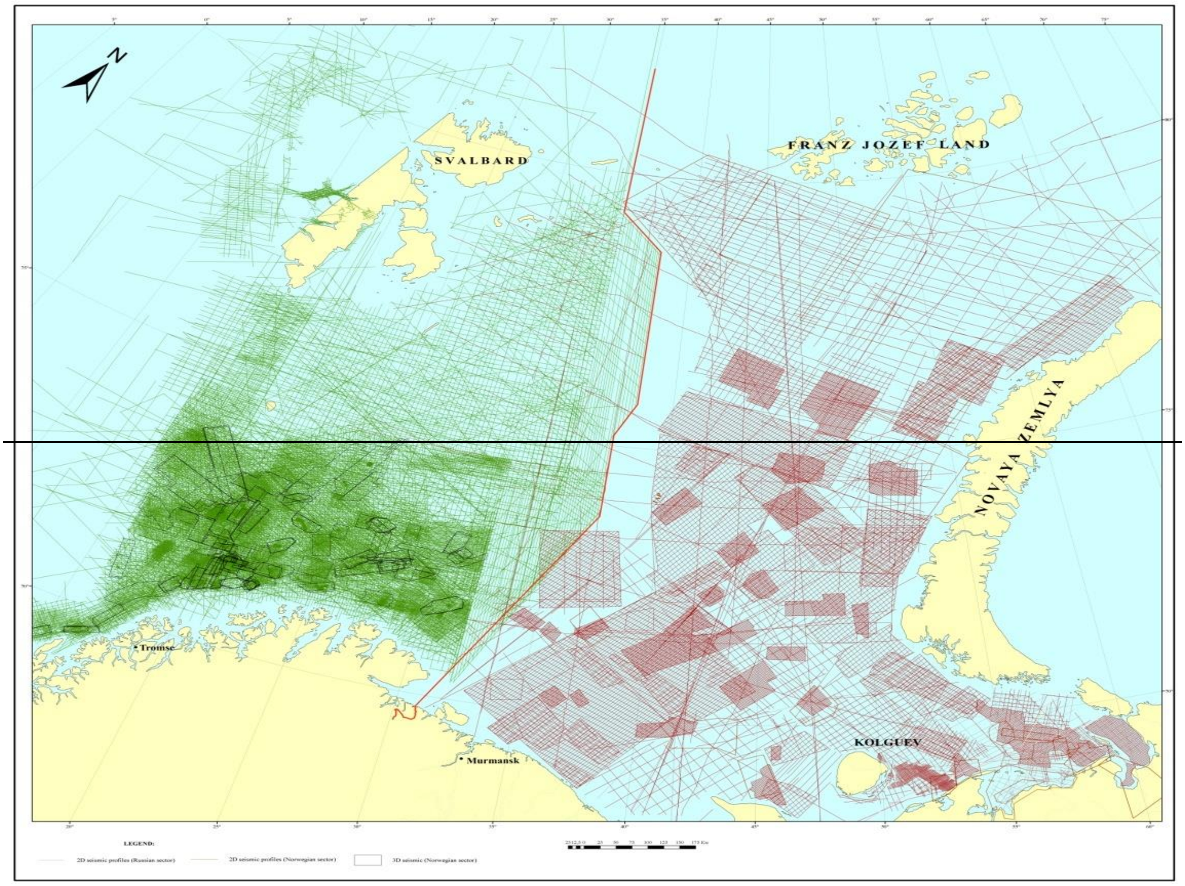


Figure 2.5.1. Map reflecting the seismic activity that has been carried out in the Barents Sea before 2014 (source: the Norwegian Petroleum Directorate and “Official report SEVMORGEO for Ministry of Natural Resources and environment "Project of Complex management Plan for Russian part of the Barents Sea", 2015).

Exploration and appraisal wells

Petroleum activities have taken place in the Norwegian part of the Barents Sea since 1980; the first discovery, 7120/8-1 Askeladd, occurred the following year. This discovery is now a part of the Snøhvit field. More than 100 exploratory wells have been drilled up to the end of 2014, resulting in 6 main discoveries: Johan Castberg; Wisting; Gotha; Alta; and the fields Snøhvit and Goliat.

Locations for 55 exploration wells in the Russian sector of Barents Sea are presented in Figure 2.5.2. According the license agreements, the plan is to drill 34 exploration wells before 2024.

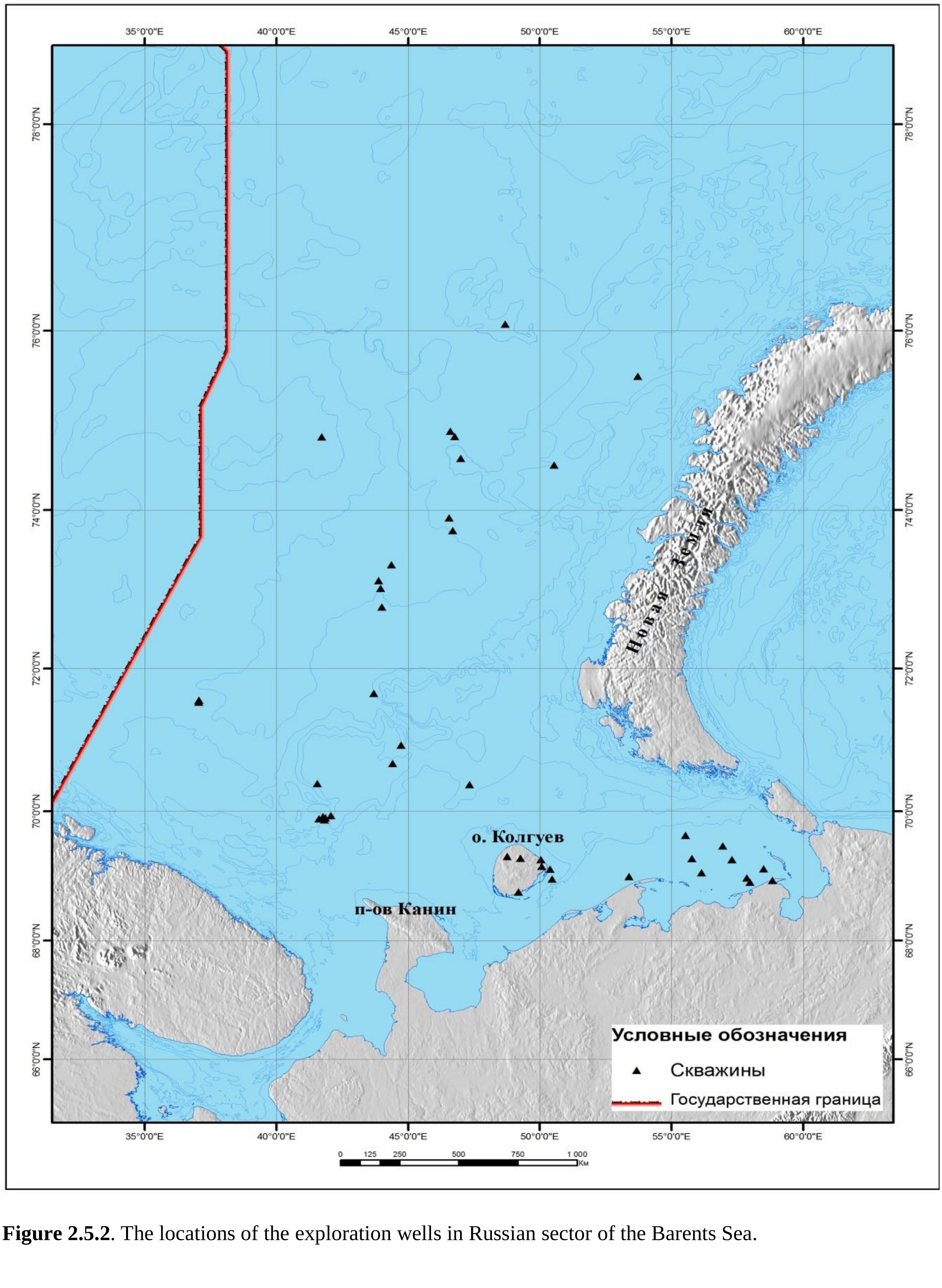


Figure 2.5.2. The locations of the exploration wells in Russian sector of the Barents Sea.

2.5.2.2 Current status of petroleum activities

Norway

In the Norwegian sector, one field in production (Snøhvit); one field will likely start production in 2016 (Goliat); another is in the planning phase (Johan Castberg).

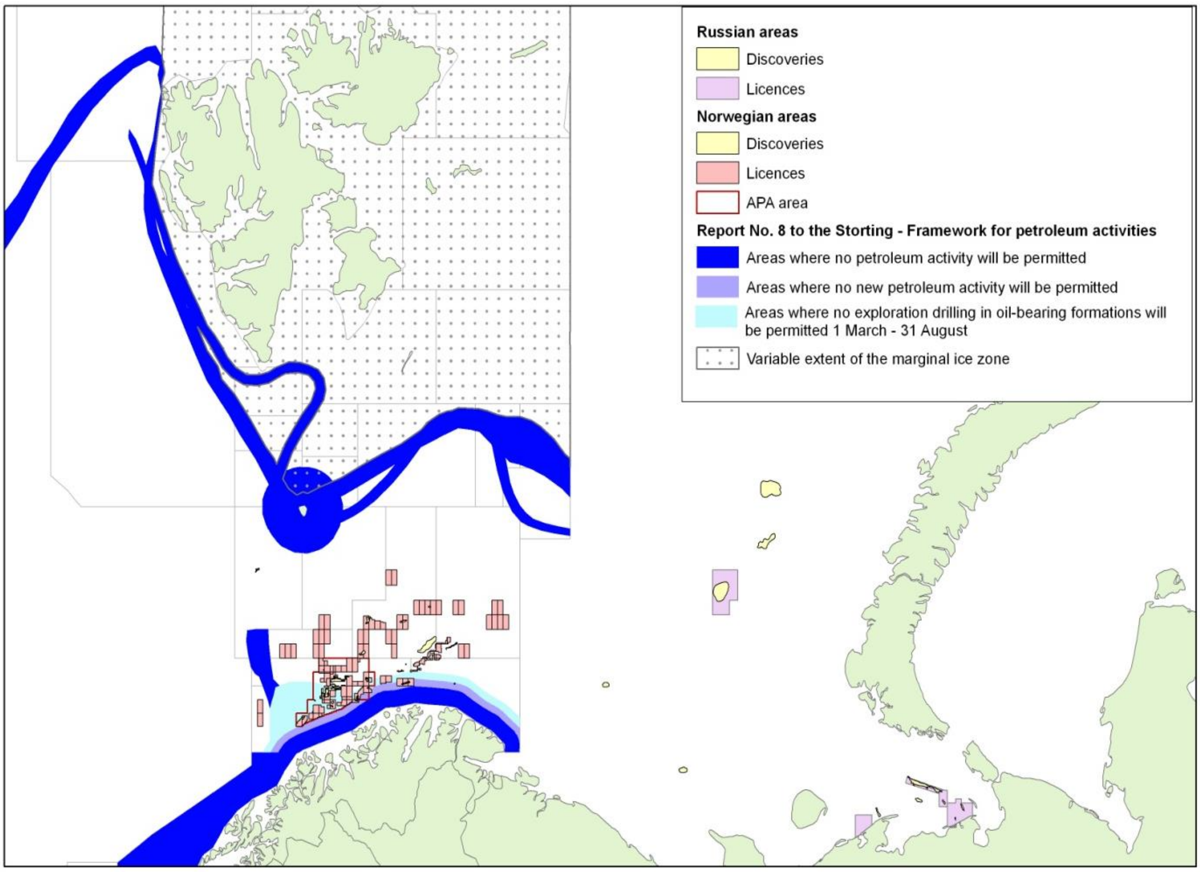


Figure 2.5.3. Map reflecting current status of petroleum activities in the Barents sea (source: the Norwegian Petroleum Directorate and Official report SEVMORGEO for Ministry of Natural Resources "Cadastre of the Russian offshore zone", 2007.

Snøhvit

Snøhvit is a gas and condensate field with an underlying thin oil zone. The field is located in the central part of the Hammerfest basin, and is developed with subsea templates with slots for 19 production wells and one CO_2 injection well. So far, nine production wells and one CO_2 injection well have been completed. Snøhvit was the first development in the Barents Sea, and has no surface installations. The gas is being transported to Melkøya outside Hammerfest in a 160 km pipeline. The field came on stream in August 2007.

Reception facilities at Melkøya outside Hammerfest take delivery of the unprocessed well stream from Snøhvit. Gas condensate, water, and CO_2 are separated before the natural gas is cooled down to liquid form (LNG), and stored in huge tanks. The gas is transported to the buyers in specially built tankers. CO_2 is transported back to the field in a separate pipeline, and is injected in a formation under the producing gas leg.

Goliat

Goliat is located 50 km southeast of Snøhvit, only 70 km from the coast of Norway, and is in the developing phase. The field is designed as a floating production and storage facility with subsea wells. Oil will be processed at the installation and transported by ship. Plans are for the associated gas to be injected into the reservoir for pressure support. Production of gas will be evaluated at a later stage. Recoverable resources at Goliat are approximately 28 million Sm^3 oil and approximately 7.5 billion Sm^3 of gas.

Johan Castberg

Johan Castberg field is located 100 km north of Snøhvit and 210 km from the coast of Norway, and is still in the planning phase. Johan Castberg includes three oil discoveries: Skrugard; Havis; and Drivis. The operation design will have a floating production facility with subsea wells. The recoverable resources in Johan Castberg are in the range 72-105 million Sm^3 oil.

Russia

Currently in the Russian sector, oil production is carried out only at the Prirazlomnoye field by means of an offshore ice-resistant fixed platform (MISP). According to the Joint Stock Company "Gazprom" press service, recoverable reserves from Prirazlomnoye are approximately 71,960,000 tonnes of oil. Commercial production at Prirazlomnoye platform began December 20, 2013. The first batch of ARCO type (Arctic Oil) was shipped on April 18, 2014, and by September 2014 MISP "Prirazlomnaya" had produced its 1st million barrels of oil.

The license to explore Prirazlomnoye field is owned by "Gazprom Neft Shelf" (a subsidiary of JSC "Gazprom Neft"). The platform is designed specifically for field development and provides all the necessary technological operations: drilling; production; storage and shipment of oil tankers; and production of heat and electricity. MISP "Prirazlomnaja" holds the distinction of being the world's first to produce hydrocarbons on the Arctic shelf from a fixed platform (artificial island) under the difficult conditions of drifting ice floes. The platform is designed to operate in extreme climatic conditions, meets the most stringent safety requirements, and is able to withstand maximum ice loads.

Extracted oil is stored in tanks located on caisson platforms with three-meter concrete walls covered with two-layer steel-plated sheets to maintain resistance to corrosion and wear. A caisson can store approximately 94 thousand tonnes (113 thousand m^3). Its margin of safety surpasses existing load standards. The platform also uses a "wet" method of storing oil that prevents ingress of oxygen in tanks and, thus, prevents the formation of explosive conditions.

Shtokman

The Shtokman gas field is located in the central part of the Russian sector of the Barents Sea shelf, about 600 km northeast of Murmansk at depths of 320-340 m. Phase I of the Shtokman project began in February 2008. "Shtokman Development AG" was set up as a joint project consisting of the three leading global corporations: JSC "Gazprom" (51%); Total SA (25%); and Statoil ASA (24%). Terms of cooperation extend 25 years from the date of commissioning. Life of the deposit is predicted to extend over 50 years. In 2012, an underwater gas pipeline (550 km in length and 36 inches in diameter - 36 inch) was completed. The gas together with gas condensate arrives from the offshore via double trunkline. Landfall is located on the northern shore of the Kola Peninsula in Opasova Bay.

2.5.2.3 Potential petroleum resources

Russia

Petroleum resources in the Russian sector of the Barents Sea are estimated to be 33,328.1 million tonnes of oil equivalent (t.o.e.). Petroleum resources of the Pechora Sea have been estimated to be 5,728.1 million tonnes of oil equivalent. Petroleum resources in the Russian sector of the Barents Sea represent 32% of the total for the Russian Arctic.

Norway

In 2014, petroleum resources in the Norwegian sector of the Barents Sea were estimated to be 510 million standard cubic meters of oil equivalents (Sm^3 o.e.); of these, 34 million Sm^3 o.e. have already been produced. Last year, due to new discoveries, the estimate for undiscovered resources in the Norwegian sector of the Barents Sea increased to 1.2 billion Sm^3 o.e.

2.5.2.4 Emission, operational, and accidental discharges

Operational discharges to the sea

The main discharge into the Barents Sea from oil and gas activities comes from drilling and well operations and from activities during the production phase. In the Russian section oil extraction on Prirazlomnoe resources is conducted with virtually “Zero discharge”.

Drilling

During drilling, two types of waste are created: used drilling fluids; and cuttings (solid material from the well bore). The harmfulness of these discharges will depend on the type of drilling fluid used. Drilling fluid consists of water or oil as a base fluid, and different kinds of chemicals. The effects of these discharges are evaluated based on their intrinsic properties, i.e., potential for accumulation in tissues, biodegradation rate, and acute toxicity.

Discharge of oil-based drilling fluids or cuttings drilled with oil based drilling fluids have been prohibited from Norwegian drilling operations since 1992 due to proven harmfulness of mineral oil. Used drilling fluids and cuttings are therefore injected into the reservoir or brought to shore for proper handling.

Water based drilling fluids contain sea water and additives which normally are not considered harmful to the environment. Discharge of used drilling fluids and cuttings drilled with water based drilling fluids are permitted in most areas of the Norwegian continental shelf.

Discharge of cuttings will lead to a certain degree of smothering of the sea bed. This has been shown so far to have very limited effect on the sea bed communities, and amount of rocks, pebbles, sand, and clay deposited is often less than deposits resulting from natural movement of solids by bottom water currents. However, special care must be taken in areas with existing or expected cold water coral and swamp communities.

Production

A form of discharge is "produced water" — water that is produced as a byproduct along with the oil, condensate, and gas. Since the 2011 revision of the Lofoten – Barents Sea Integrated Management Plan, discharge of produced water has been allowed in the Norwegian section of the Barents Sea under the same conditions as for the rest of Norway's continental shelf. Produced water contains: dispersed oil (small oil droplets); dissolved oil; and naturally occurring chemical components like heavy metals (e.g., lead and chromium) and radionuclides (226Ra and 228Ra); and organic compounds (i.e., inter alia carboxylic acids, volatile fatty acids (acetic acid), BTX (benzene, toluene and xylene), phenols, PAH (polyaromatic hydrocarbons), and alkyl phenols.

During the early years of oil production, amounts of produced water were usually low, but the water/oil ratio increases over time (80 – 95 % water content is not uncommon from some old fields in the North Sea). In most Norwegian waters, produced water is injected into the formation or discharged into the sea — if the dispersed oil content and the Environmental Impact Factor are sufficiently low. Other types of fluids which may occur are: drainage water; cooling water; household water; and sewage water.

Large amounts of chemicals are used during drilling and production. Treatment and disposal of these chemicals follow the same procedures as for produced water. The effects of chemical discharge are evaluated based on their intrinsic properties (potential for accumulation in tissue, biodegradation rate, and acute toxicity) and their contribution to the Environmental Impact Factor.

Air Emissions

Offshore oil and gas activities contribute to air pollution, e.g., CO_2 emissions, NOx, non-methane volatile organic compounds (NMVOC), methane, soot/black carbon, and SO_2. Emissions arise from energy production, gas flaring, and venting (release of unburned gas from pipes and valves in normal operational processes.

Noise

Noise from seismic surveys, drilling, and production may have an effect on fish and marine mammals.

Accidental discharge

During drilling and production activities, there is always a risk of accidental discharge. Most accidental discharge of oil or chemicals is small, and caused by overfilling tanks, leakage from pipes or transfer lines, loose fittings or couplings, and valves that have been left open. Pipeline ruptures also may occur.

Blowouts are very uncommon, but could result in large amounts of oil being released. A blowout may occur if there is a loss of control during exploratory drilling due to lack of knowledge about the geology in the area.

Other large technical failures, e.g., pipeline breakage, refilling lines, etc., may also cause large spills.

2.5.3 Maritime transport/shipping

O. Korneev (SMG) and A. Bambulyak (Akvaplan-niva)

2.5.3.1 Shipping activity

In number, fishery activities currently account for most shipping traffic. The cruise vacation industry contributes to annual and seasonal variations in the amount of shipping traffic. A large share of goods to, or circulated within, Norway's three northernmost counties are transported by ship. Marine shipping is also very important for Russia; connecting territories with each other, and playing a vital role in external economic activities. Marine shipping plays a central role, and remains essential, in supporting the life of coastal communities in Russia.

The largest liquid commodity transported by ship is oil (crude oil and oil products) being carried — from northern Russia and northern Norway to destinations in Europe and North America — by LNG (Liquefied Natural Gas) and LPG (Liquefied Petroleum Gas) tankers from Melkøya to Norwegian and Russian oil depots. In 2013, nine terminals in the Russian Arctic from Ob Bay (Kara Sea) to Kola Bay (Barents Sea) received crude oil, oil products, and gas condensate for export via production pipelines, river tankers, railways over land, and ship cargo vessels. A number of small tankers traveled from these terminals to European and American destinations, but most petroleum cargo was transhipped in ice-free areas of the Barents Sea, at FSO (Floating, Storage, Offloading) in the Kola Bay or STS (ship-to-ship transfer) terminals in Northern Norway. According to Russian port administrations, customs, and operators, petroleum terminals in the Russian arctic offloaded for export between 9 and 15 million tons of liquid hydrocarbon annually during the period from 2004 to 2013 (Figure 2.5.4).

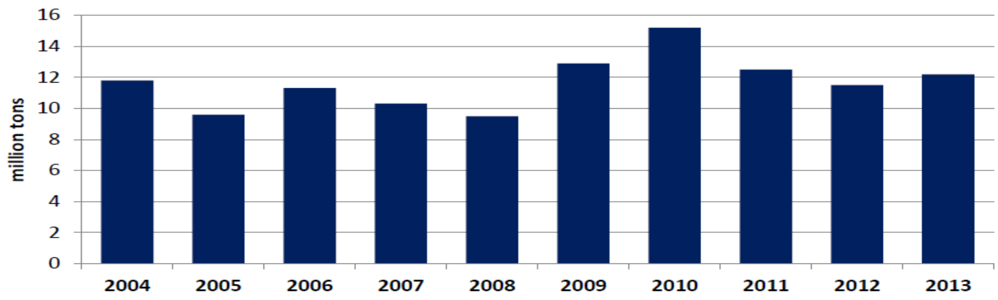


Figure 2.5.4. Liquid hydrocarbons exported from the Russian Arctic through the Barents Sea (Bambulyak et al., 2015a).

The largest crude oil export terminal (Varandey) with a capacity of 12.5 million ton/year was set in operation in June 2008. In 2009, it transported 7.4 million tons of crude oil for export. In 2012, Varandey's export volume dropped to 3.1 million tons, but again increased in 2013 to 5.4 million tons, as new onshore oil fields were connected to the terminal via the pipeline grid. It was predicted that up until 2015, Varandey and other terminals would ship between 10 and 15 million tons of Russian crude oil, gas condensate, and refined products for export over the Barents Sea. These annual volumes will increase with increased oil production and shipment from Prirazlomnaya platform in the Pechora Sea; this platform began production of commercial oil in December 2013, and is expected to offload 6 million tons of crude oil when reaches maximum production level. Two new ports and petroleum export terminals have been constructed in Ob Bay (Kara Sea): Sabetta port will have an annual export capacity of 30 million tons and ship 16.5 million tons of LNG and gas condensate from Yamal LNG when completed; also the offshore terminal in Novy Port is constructed to offload 8 million tons of crude oil per year.

In addition to transport of Russian oil and petroleum products on the Barents Sea, in 2007 Snøhvit gas field and the LNG plant on Melkøya started production and shipment of gas condensate, LNG, and LPG. Also in 2007, Melkøya offloaded 67,000 tons of gas condensate and 131,000 tons of LNG. In 2008, they shipped almost 2 million tons of gas products a year. During 2009-2013, the plant offloaded between 4 and 5 million tons of liquid hydrocarbons annually, mostly as LNG.

Analyses of tanker traffic indicate that types of petroleum cargo have varied from year to year. While terminals in the Kara- and the Pechora Sea have offloaded crude oil and gas condensate produced in their immediate areas, port terminals in the White- and the Barents Sea have handled light and heavy petroleum products and gas condensate delivered long distances by railway. In 2013, crude oil, mostly from Varandey, had the largest share (46%) of petroleum cargo volume exported from Russia through the Barents Sea; gas condensate had the second largest share. In coming years, it is expected that the share of crude oil will increase due to both an increase in oil shipments from Varandey and Prirazlomnaya, and a decrease in gas condensate shipments from terminals in the White Sea due to a new terminal being put on stream in Ust'-Luga in the Baltic Sea (Bambulyak et al., 2015b).

2.5.3.2 Ship to ship (STS) transfer

The first STS terminal was established in Kola Bay of the Barents Sea in 2002. During 2002-2004, five more STS and FSO (Floating Storage and Offloading vessel) terminals were established in Ob Bay of the Kara Sea, Onega Bay of the White Sea, and the Kola Bay. The STS terminal in Onega Bay transhipped heavy fuel oil in 2003, and was closed after an accidental oil spill. The STS terminal in the Ob Bay tranships crude oil from Western Siberia during summer and sends it either to Belokamenka FSO in the Kola Bay or directly to major West European ports. Two STS terminals near Murmansk in the Kola Bay are used for transhipments of petroleum cargo brought from Murmansk or gas condensate from Dudinka. Belokamenka receives mostly crude oil produced in Timano-Pechora oil-and-gas bearing province and shipped from Varandey; it can also be used for transhipment of Prirazlomnoye oil. A heavy fuel oil export terminal in Mokhnatkina Pakhta in Kola Bay also uses a FSO.

In the Norwegian section of the Barents Sea, STS transfer of petroleum products has been carried out since 2002 in two fjords in Finnmark, Bøkfjord, and Sarnesfjord. Gas condensate is the main product being transhipped at these locations by the end of 2013; however, there are pending applications for STS and FSO transfer of other products, including crude oil. A project has been launched to construct an oil depot and offloading terminal in Kirkenes, Finnmark, Norway with a planned capacity of up to 20 million tons per year. The terminal is planned for transhipment of crude oil from the Russian arctic (Bambulyak et al., 2015a, 2015b.

Shipping lanes have been established for tankers sailing along the coast; use of these lanes is obligatory in the Norwegian section of the Barents Sea, but traffic to and from STS transfer sites in the fjords goes closer to land. Transfer of petroleum products made in the fjords — either at dockside or under anchor — is considered to be Norwegian industrial activity; it, thus, falls under control of the Norwegian Environmental Agency (MDir) and the Norwegian Coastal Administration (Kystverket). STS transfers made outside Norwegian territorial waters — as long as the ships operate under their own engine power — are subject to provisions of the MARPOL 73/78 (International Convention for the Prevention of Pollution from Ships) Convention, Annex I. "MARPOL" is short for marine pollution and 73/78 is short for the years 1973 and 1978.

2.5.3.3 Discharge from maritime transport

Day-to-day impacts of shipping on the environment are caused by ordinary operational discharge. Discharge of sludge and oily bilge water from machinery and discharge of oil and oily mixtures (slops) from cargo areas is regulated internationally under the MARPOL Convention. The Convention permits a certain level of discharge of oily bilge water and oily mixtures from tank washings. However, all ships are required to have separate ballast tanks, and this can almost eliminate discharge of oily ballast water. Sea surface oil slicks with unidentified sources are reported every year; most are assumed to come from illegal discharge from ships.

2.5.3.4 Introduction of non-indigenous species

Maritime transport to Norway and tanker traffic to Northwest Russia is currently dominated by vessels from large European ports; also a small number of vessels sail from Asia along the Northern Sea Route (NSR). These vessels tend to call at ports in the same biogeographic area, and take on ballast water from areas where the flora and fauna is similar to that in the Barents Sea. However, there is a risk to further spread non-indigenous species which are already established, either ballast water or attached to ships' hulls. Other categories of vessels, such as general cargo and container ships, operate in a global market; many of which likely come from foreign ports in other biogeographic zones, but where physical and chemical conditions are similar to those in Barents Sea. In the future, there may be increased risks associated with use of NSR combined with a failure to properly treat ballast water.

2.5.4 Other human activities

2.5.4.1 Marine Tourism

Tourism is one of the largest and steadily growing economic sectors world-wide. Travel excursions to the far north have increased considerably in recent decades; currently nearly one million tourists visit the Barents Sea region annually. Tourist fishing has become a growing industry along the Norwegian Barents Sea coast. There also is a long tradition of small-scale subsistence fishing for citizens in both Norway and Russia.

2.5.4.2 Aquaculture

Large-scale commercial aquaculture operations took off in the 1980s. Since then, salmon aquaculture has experienced remarkable growth as a result of expanded new culture locations, improved productivity, enhanced husbandry and management practices, and growing global markets (Liu et al., 2011). Notably, in a few decades salmon farming has dramatically expanded to the extent that farmed salmon has replaced wild salmon in both production and markets. Different types of aquaculture are conducted in the Barents Sea:

1) The most common production is open-sea cage farming of Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*);
2) Other marine species such as Atlantic cod (*Gadus morhua L.*) and halibut (*Hippoglossus hippoglossus L.*) are produced to a lesser extent;
3) Blue mussel (*Mitulus edilus*) farming is conducted in sea, with natural seeding;
4) On-shore fish farming of species such as Arctic charr/Arctic char (*Salvelinus alpinus*) and sea trout (*Salmo trutta*) is also possible in Arctic areas if clean water and energy for heating is available (Taramger et al., 2014).

Norway

In Norway, production of farmed fish has risen sharply — since the industry was established at the beginning of the 1970s as a supplement to agriculture — to the point that Norway now accounts for about half of the world production of farmed Atlantic salmon (*Salmo salar*). During the last 40 years aquaculture has become an important industry, especially for small coastal communities, and an important source of foreign exchange. Most Norwegian Sea farms are cage systems located in deep, sheltered fjords (FAO, 2015). Atlantic salmon and rainbow trout farmed in sea cages are the two most important species farmed in Norway, representing approximately 97 % of total production volume and value. In 2009, other important farmed species in volume were rainbow trout and cod. Shellfish are also cultivated, including: mussels (1,649 tonnes in 2009); European flat oysters (*Ostrea edulis*); and scallops. Of these species, mussels are the most important both in terms of value and volume (FAO, 2015).

Russia

The Russian Federation has a long marine coastline (approximately 60,000 km) with large areas in the Barents Sea which are suitable for aquaculture operations. The Murman Barents Sea coastal region can be divided into 3 unequal areas based on environmental conditions for aquaculture purposes: 1) from the Norwegian border to the Rybachiy-Sredniy Peninsula; 2) from the Rybachiy-Sredniy Peninsula to Kola Bay; and 3) from the eastern part of the Kola Bay to Teriberka Bay. In Russia, the aquaculture industry began in the 1970s, although some scientific-technical development had been carried out since the end of 1960s. Salmon and sturgeon (*Acipenser gueldenstaedtii*) breeding have an even longer history (Moyseev et al., 1985; VNIRO, 1998; Bagrov, 2004). The first Russian commercial fish farming in the Barents Sea was initiated in 2005 in Pechenga Bay and Ambamaya Bay. In 2012, Atlantic salmon farming was started in the Ura Bay. After a decrease in production during the mid 1990s due to market-related factors, new developments in the sector have taken place, including: a wider range of cultured species; a shift to semi-intensive methods; and use of modern feeding methods. In Russia, marketing fish products operates on three levels: local; regional; and federal. National production of farmed Atlantic salmon is entirely targeted at the domestic market as an alternative to imported Atlantic salmon. The only aquaculture products exported are sturgeon and trout eggs (FAO, 2015).

2.5.4.3 Bioprospecting

Marine bioprospecting may be defined as the systematic search for bioactive molecules and compounds from marine sources which have new and unique properties, as well as the potential for commercial applications, including: medicines; foods and feeds; textiles; cosmetics; and the process industry. The Barents Sea, where temperate waters from the Gulf Stream and cold waters from the Arctic meet, is home to diverse organisms, which are well adapted to the extreme conditions of their marine habitats. This high species biodiversity represents a correspondingly rich source of chemical diversity, and there is growing scientific and commercial interest in the biotechnological potential of that biodiversity. This makes these arctic species attractive for marine bioprospecting (Leary, 2008).

2.6 Ecosystem interactions

M.M. McBride (IMR), S. Boitsov (IMR), P. Fauchald (NINA), A. Filin (PINRO), Å. Høines (IMR), E. Johannesen (IMR), J. Klungsøyr (IMR), O. Korneev (SMG), P.R. Makarevich (MMBI), M. Skern-Mauritzen (IMR), J.E. Stiansen (IMR), and A.B. Storeng (DN)

2.6.1 Abiotic impact

Physical conditions in the Barents Sea are largely determined by three main water masses: Coastal Water; (North) Atlantic Water; and Arctic Water. These three water masses are linked to three different current systems: the Norwegian Coastal Current; the Atlantic Current; and the Arctic Current. Climatic variability is determined by their properties and the activity of inflowing Atlantic Water. Variations in activity of these currents may be explained by external forcing, but may also be a result of processes taking place in the Barents Sea itself. Year-to-year variability in sea temperatures is profoundly influenced by the relatively warm Atlantic water masses flowing in from the southwest (Loeng, 1991) as well as regional heat exchange with the atmosphere (Ådlandsvik and Loeng 1991; Loeng et al. 1992). The inter-annual variability is, to a large extent, determined by conditions during winter, the season when differences in temperature — between both inflowing and local water masses, and between the local atmosphere and the sea surface — are at their highest (Ottersen and Stenseth, 2001).

Ottersen and Stenseth (2001) demonstrate that climatic processes on the scale of the North Atlantic basin may profoundly influence the ecology of the highly productive Barents Sea. The impact of inter-annual and decadal shifts in regional climate — sea temperature in particular — on fish recruitment in the Barents Sea has also been well documented (Sætersdal and Loeng, 1987; Ottersen and Sundby, 1995). In the Barents Sea ‘‘warm’’ years are good years production-wise for three principal reasons: 1) a larger ice-free area allows for higher primary productivity; 2) warm years imply large influxes of zooplankton from the south into the Barents Sea, and; 3) higher temperatures lead to higher biological activity at all trophic levels (Sakshaug, 1997). As a result, above-normal sea temperatures tend to have a positive impact on fish production.

Climatic fluctuations have a significant effect on the ice conditions, which in turn influence the biological production in the northern Barents Sea (Loeng, 2007). The composition and migratory habits of living organisms in the Barents Sea are determined by the contrast of the environmental conditions between the Atlantic and the local water masses (Matishov, 1986a). Bottom-up processes are important as changes in climate conditions (e.g. warming and reduced sea ice extent) will likely influence the timing and magnitude of phytoplankton blooms and thus influence primary productivity of the Barents Sea (Dalpadado et al., 2014). Despite high interannual variability, the ice extent in the Barents has decreased by 60% over the last 200 years (Vinje, 2001; Wassmann et al., 2006).

Productivity in the Barents Sea is responsive to loss of sea ice, but the location of storm tracks in creating additional mixing to fuel nutrient replenishment is also an important factor (Drinkwater, 2011). Inflowing Atlantic Water largely controls nutrient concentrations in the southern and central Barents Sea. Thus, winter concentrations are typical for the North East Atlantic; these water masses have recently been exposed to biological production as surface waters. The spatial distribution of new production and phytoplankton biomass in the Barents is strongly linked to nutrient consumption during the productive period (May–early September) and vertical mixing during winter (Wassmann et al., 2006).

2.6.2 Biotic interactions

The microbial loop is an important pathway for channeling carbon through the food web. Studies of the microbial food web in the Barents Sea are scarce, but they are essential for a more balanced understanding of the pelagic ecosystem. Scattered investigations in the Barents Sea indicate that small planktonic forms including microbes are prevalent (e.g., Thingstad and Martinussen, 1991; Hansen et al., 1996; Hansen and Jensen, 2000; Arashkevich et al., 2002; Verity et al., 2002; Wassmann et al., 2005). Investigations close to the Barents Sea entrance (Verity et al., 1999) and in its marginal ice zone (Verity et al., 2002) suggest that often more than half of the dominant pico- and nano-plankton cell biomass is heterotrophic. Indeed, most microbes are heterotrophic, using organic compounds as both carbon and energy sources (Wassmann et al., 2006).

The food web has 5-6 trophic levels: phytoplankton → zooplankton → pelagic fish → demersal fish → sea birds → marine mammals (including polar bear *Ursus maritimus*). Species diversity is relatively high compared to other Arctic seas. A total of 3,245 faunal taxa have been recorded in the Barents Sea (Sirenko, 2001). Of this total, benthic macrofauna (60%) and meiofauna (34%) comprise the vast majority of known species. Most (80%) of the total benthic faunal biomass can be identified within 24 taxa, with 50% attributable to only 8 species. These benthic organisms — bottom assemblages of fish and invertebrates, both commercial and non-commercial — channel a significant part of the energy flow through the system (Wassmann et al., 2006) (Figure 2.6.1).

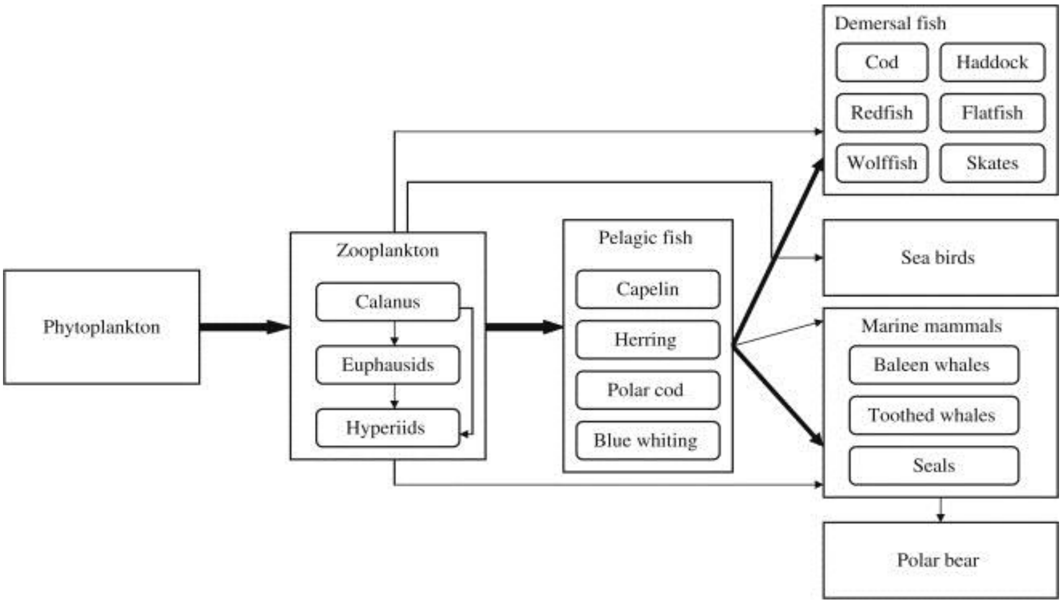


Figure 2.6.1. General scheme of food web in the Barents Sea ecosystem (From Yaragina and Dolgov, 2009).

As in other marine systems, phytoplankton constitutes the main source of primary production in the Barents Sea. As such, changes in annual phytoplankton production — in response to variability in climate and oceanographic conditions — will directly affect overall functioning of the marine ecosystem. Zooplankton species form the trophic link between phytoplankton (primary production) and organisms higher in the food chain. Hence, favorable conditions for the phytoplankton bloom/primary production at the ice edge — as it retracts during summer and autumn — temporarily support large concentrations of zooplankton species which are forage for fish, seabirds, and mammals. Blooms in Atlantic waters are not as intense as blooms at the ice edge; they occur over a longer period of time, however, and result in higher total phytoplankton production. Primary production increases rapidly in spring, when mixed-layer depth decreases above the critical depth and algae receive sufficient light to grow and accumulate. This may take place earlier in the marginal ice zone where ice-melt and brine formation induce an early stratification. Production acceleration in the more southern Atlantic Water depends on a more slowly evolving thermal stratification (Falk-Petersen et al., 2000; Wassmann et al., 2006).

The spring bloom in Atlantic Water is of particular importance for reproduction of *Calanus finmarchicus* — the predominant herbivorous copepod in the central Barents Sea. It has an annual life cycle, and each new generation develops during spring and summer, being nourished by the seasonal phytoplankton bloom. Carnivorous zooplankton such as amphipods (Themisto spp.) may feed on *C. finmarchicus* in competition with plankton-feeding fish such as capelin and herring. At the same time, carnivorous zooplankton species become prey for these same fish species. Among the omnivorous zooplankton, krill species (e.g. Thysanoessa spp.) are regarded as the most important. The main zooplankton species on the Atlantic side of the Barents Sea are *C. finmarchicus* and *Thysanoessa inermi*; whereas in Arctic waters larger species such as *Calanus glacialis* and amphipods (*Thermisto libellula*) dominate (Melle and Skjoldal, 1989; Dalpadado and Skjoldal, 1996; Dalpadado, 2002; Ellingsen et al., 2008). Variability in temperature, salinity, wind conditions, and sea-ice dynamics affect primary (phytoplankton) and secondary (zooplankton) production (Rey, 2004; Wassmann et al., 2006). During cold climatic periods, primary production in the Barents Sea can decrease due to increased ice coverage and, hence, reduced area for production. This may in turn result in reduced secondary production during cold periods (Yarangina and Dolgov, 2009).

Small pelagic planktivorous fish exert bottom-up control on top predators, depriving the latter of energy-optimal food resources, as well as top-down control on mesozooplankton (Yarangina and Dolgov, 2009). The capelin is a specialized plankton feeder, the most important planktivorous fish, and an ecological keystone species in the Barents Sea (Hamre, 1994; Gjøsæter, 1998). Capelin graze heavily on lipid-rich mesozooplankton — primarily copepods, euphausiids, and amphipods —and, thus, represent a crucial link between lower- and higher-pelagic trophic levels. Schools of capelin undertake annual feeding migrations to the north, generally following the marginal ice zone bloom with its subsequent zooplankton growth. Northward migrating capelin, forming the ‘‘capelin front’’, deplete their own feeding grounds of available prey in a relatively short time (Hassel et al., 1991); they constitute a rich food source for marine mammals (e.g., Folkow et al., 2000; Nilssen et al., 2000). Other fish at the same trophic level include juvenile herring, polar cod, blue whiting, and several other species during their 0-group stages (Hamre, 1994; Bogstad et al., 2000; Gjøsæter and Ushakov, 2003; Wassmann et al., 2006).

Cod is the top predator in the Barents Sea; its diet is a good indicator of the state of the ecosystem. Capelin is the most important prey for cod (Bogstad and Mehl, 1997; Bogstad and Gjøsæter, 2001). Other important prey items for cod include: krill (Euphausiacea); polar cod; amphipods (mainly Hyperiidae); shrimp (*Pandalus borealis*); haddock (*Melanogrammus aeglefinus*); herring; blue whiting (*Micromesistius poutassou*); and juvenile cod. It may also consume significant amounts of adult herring (Bogstad and Mehl, 1997). Apart from cod, other abundant piscivorous fish stocks in the Barents include: haddock; deep-sea redfish (Sebastes spp.); Greenland halibut (*Reinhardtius hippoglossoides*); long rough dab (*Hippoglossoides platessoides*); and thorny skate (*Raja radiata*) (Bogstad et al., 2000; Dolgov, 2002). In recent years, biomass estimates for other piscivorous fish species in the Barents have been low compared to that of cod and haddock (Eriksen (Ed.), 2014) (Table 2.6.1). Based on available information on the diet and consumption of these species, less than half the total prey consumed is fish (Wassmann et al., 2006).

The Barents Sea has a diverse and abundant seabird community; and one of the largest concentrations of seabirds in the world (Norderhaug et al., 1977; Anker-Nilssen et al., 2000). These common and ecologically important species acquire all or almost all of their diet from the sea — where they consume considerable amounts of fish and invertebrates — and remain within the Barents Sea region during a substantial part of the year. The consumption of marine prey by birds results in a large return of nutrients to the marine ecosystem as excrement (Zelikman and Golovkin, 1972; Wassmann et al., 2006). Peak seabird abundance occurs in the spring–summer season. An estimated 20 million seabirds harvest approximately 1.2 million tons of biomass from the Barents Region annually (Barrett et al., 2002). In doing so, they play an important role in transporting organic matter and nutrients from the sea to the land (Ellis, 2005). This transport has particular significance for production in the Arctic, where lack of nutrients can be an important limiting factor. While most seabirds migrate out of the Barents during winter, some species remain throughout the year. Sea ice conditions affect their abundance. ‘‘Warm’’ years with little ice show a higher number of guillemots in at-sea surveys of the Barents compared to ‘‘cold’’ years (Erikstad et al., 1990). The distribution of seabirds in the Barents is mainly determined by food availability and distribution. During winter and spring, most seabirds are found close to the food-rich ice edge and the Polar Front. In spring and summer, most seabirds are concentrated around breeding colonies. Major seabird colonies are found on Bear Island, Hopen, southeastern part of Svalbard, Troms and Finnmark County, the Murman and Nenets coasts, Novaya Zemlya, and Franz Josef Land (Wassmann et al., 2006).

Table 2.6.1. Estimates of abundance (N, million individuals) and biomass (B, thousand tonnes) of the main demersal fish species in the Barents Sea for the 2004-2014 period (Eriksen (Ed.), 2014).

Year		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	**2014**	LTM
Atlantic wolffish	N	14	15	26	42	25	20	17	20	22	27	↓12	23
	B	7	6	11	11	14	8	17	13	9	30	↓12	13
Spotted wolffish	N	12	11	12	12	13	9	7	9	13	13	↓8	11
	B	31	92	46	42	51	47	37	47	83	84	↓51	56
Northern wolffish	N	3	3	2	3	3	3	3	6	8	12	↓6	5
	B	26	26	19	25	22	31	25	42	45	52	↓34	31
Long rough dab	N	2957	2910	3705	5327	3942	2600	2520	2507	4563	4932	↓3046	3596
	B	311	280	378	505	477	299	356	322	584	565	↓413	408
Plaice	N	52	19	36	120	57	21	34	36	21	36	↑170	43
	B	43	11	19	55	29	13	21	26	13	29	↑121	26
Norway redfish	N	39	110	219	64	24	17	26	83	114	233	↓105	93
	B	4	15	19	10	4	2	2	9	12	25	↓6	10
Golden redfish	N	13	23	16	20	42	12	22	14	32	75	↓45	27
	B	9	11	16	11	17	11	4	5	8	20	↓13	11
Deep-water redfish	N	263	336	526	796	864	1003	1076	1271	1587	1608	↓927	933
	B	106	143	219	183	96	213	112	105	196	256	↓208	163
Greenland halibut	N	182	358	430	296	153	191	186	175	209	160	↓43	234
	B	39	53	77	86	76	90	150	88	86	94	↓53	84
Haddock	N	757	1211	3518	4307	3263	1883	2222	1068	1193	734	↑1110	2016
	B	261	342	659	1156	1246	1075	1457	890	697	570	↑630	835
Saithe	N	36	31	28	70	3	33	5	9	14	18	↓3	25
	B	41	26	49	98	7	29	9	10	13	33	↓6	32
Cod	N	1513	1012	1539	1724	1857	1593	1651	1658	2576	2379	↓1373	1750
	B	1074	499	810	882	1536	1345	2801	2205	1837	2132	↓1146	1512
Norway pout	N	620	1026	1838	2065	3579	3841	3530	5976	3089	2267	↓1254	2783
	B	13	14	32	61	97	131	103	68	105	40	↓37	66

Marine mammals are consumers of production at several trophic levels in Arctic systems, and because of their large body size and the abundance of some species, they are thought to have an important top-down influences on the structure and function at lower levels of the food web (Bowen, 1997). Marine mammals which have adapted to become year-round residents in the Barents Sea include: walrus (*Odobenus rosmarus*); ringed seal (*Phoca hispida*); bearded seal (*Erignathus barbatus*); white whale (*Delphinapterus leucas*); narwhal (*Monodon monoceros*); and bowhead whale (*Balaena mysticetus*). Harp seal (*Pagophilus groenlandicus*) is a resident in both the Arctic and sub-Arctic parts of the Barents Sea. Harbour seal (*Phoca vitulina*) reside year-round in the Arctic at Svalbard, but this species, along with the grey seal (*Halichoerus grypus*), has a range that is rather restricted to north-temperate areas, i.e., in the southern parts of the Barents Sea. Marine mammals which seasonally migrate to the Sea include: Minke whale (*Balaenoptera acutorostrata*); fin whale (*B. physalus*); humpback whale (*Megaptera novaeangliae*); white-beaked dolphin (*Lagenorhynchus albirostris*);

harbour porpoise (*Phocoena phocoena*); and to a lesser extent killer whale (*Orcinus orca*) and blue whale (*Balaenoptera musculus*) (Wassmann et al., 2006).

2.6.3 Human impact(s)

The Barents Sea is strongly influenced by human activity: historically, involving the fishing and hunting of marine mammals. More recently, human activities also involve marine transport of goods, oil and gas, tourism, aquaculture, and bioprospecting.

Fishing is believed to have the largest human impact on the fish stocks in the Barents Sea, and thereby on the functioning of the whole ecosystem. However, observed variations in both fished species and the ecosystem as a whole are also the effect of other pressures such as climate and predation.

A reduction in fuel consumption per kilogram (kg) fish caught by the Norwegian fishing fleet has been observed in recent years. Purse seiners and coastal seiners have the lowest fuel consumption per kg fish caught (0.07-0.08 ltr/kg fish); whereas long-liners, small coastal vessels, and the bottom trawlers have higher fuel consumption (from 0.17-0.34 ltr/kg fish). All fleets have managed to reduce their fuel consumption in recent years.

The Barents Sea remains relatively clean with low pollution levels compared to marine areas in many industrialized parts of the world. Major sources of contaminants in the Barents Sea are natural processes, long-range transport, accidental releases from local activities, and ship fuel emissions.

The Barents Sea can become an important region for oil and gas development. Currently offshore development is limited both in the Russian and Norwegian economic zones (to the Snøhvit field north of Hammerfest in the Norwegian sector), but this may increase in the future with development of new oil- and gas fields. In Russia there are plans for the development of Stockman, a large gas-field west of Novaya Zemlya. The environmental risk of oil and gas development in the region has been evaluated several times, and is a key environmental question facing the region as well as an area of popular concern (Hiis Hauge et al., 2013) (Figure 4.4.9).

Transport of oil and other petroleum products from ports and terminals in northwest-Russia increased over the last decade. In 2002, about 4 million tons of Russian oil was exported along the Norwegian coastline, in 2004, the volume reached almost 12 million tons, but the year after it dropped, and from 2005 to 2008 was on the levels between 9.5 and 11.5 million tons per year. In a five-ten years perspective, the total available capacity from Russian arctic oil export terminals can reach the level of 100 million tons/year (Bambulyak and Frantsen, 2009). Therefore, the risk of large accidents with oil tankers will increase in the years to come, unless considerable measures are imposed to reduce such risk.

Tourism is one of the largest and steadily growing economic sectors world-wide. Travels to the far north have increased considerable during the last 15 years, and there are currently nearly one million tourists annually visiting the Barents Region.

The high biodiversity of the oceans represents a correspondingly rich source of chemical diversity, and there is a growing scientific and commercial interest in the biotechnology potential of Arctic biodiversity. Researchers from several nations are currently engaged in research that could be characterized as bio-prospecting.

Aquaculture is growing along the coasts of northern Norway and Russia, and there are several commercial fish farms producing salmonids (salmon, trout), white fish (mainly cod) and shellfish.

Both human-induced climate change and ocean acidification may have large impacts on the Barents Sea ecosystem in the future. Accordingly, interest has increased in determining the most likely ecosystem response.

2.6.3.1 Overfishing

Barents Sea fish stocks undergo large variations in recruitment related to variations in environmental factors and interactions between species, including birds and marine mammals. The ecosystem has an inherent tendency to fluctuate between: 1) periods of strong cod and herring recruitment with reduced capelin stock size; and 2) periods when herring are largely absent, cod recruitment is moderate, and the capelin stock is large (Gjøsæter, 1995).

Fisheries for pelagic stocks also strongly impact the ecosystem by intensifying these inherent fluctuations (Gjøsæter, 1995). Overfishing clearly contributed to complete collapse of the herring stock at the end of the 1960s (Dragesund et al., 1980), and may also have contributed to the capelin stock collapse in the mid-1980s. At the same time several gadoid stocks collapsed (cod, haddock, and saithe) (Nakken, 1998).

As such, an important effect of fisheries for pelagic stocks in the Barents Sea is to increase the instability in the entire ecosystem. The reduced herring stock in 1983 limited its potential to rebuild following good recruitment conditions in 1983-85. Subsequent herring year classes were therefore too small to support the cod stock, and the capelin stock was more heavily preyed upon. The cod stock suffered from a food shortage; growth declined and mortality increased due to both cannibalism and fishing mortality. The result was that all three stocks were heavily reduced, and the crisis at the fish level of the ecosystem had severe effects on the higher levels of the food web, e.g. dying seals and birds, and led to economic ruin for many fishermen (Gjøsæter, 1995).

2.6.3.2 Habitat destruction (bottom trawling)

There is generally wide species diversity on the seabed. Russian researchers have identified approximately 2,700 species of benthic animals in the Barents Sea; comprising approximately 80% of the total fauna in the region. Fishermen have long reported that in some areas sponges and corals dominate the seabed. New coral reefs are continually being described along the coast of Norway where they are found mainly at depths of between 200 and 600m (Buhl-Mortensen, 2006). Some 109 species of sponge are found along the coast of Norway in the Barents Sea, but information about the geographic distribution of sponge colonies is limited.

These cold-water coral reefs, coral gardens, and sponge aggregations provide habitat for a variety of fish and invertebrates and thus represent hotspots of biodiversity and carbon cycling in the Barents Sea. *Lophelia pertusa* forms coral reefs, while horn corals (e.g., *Paragorgia arborea, Paramuricea placomus*, and *Primnoa resedaeformis*) may form coral forests, with colonies up to three meters high (Buhl-Mortensen, 2006).

These high-latitude habitats are dominated by large sessile fauna; many of which are K-selected and have: slow growth rates, relatively long life spans, low reproduction rates, and are important for energy transmission in the ecosystem (MacArthur and Wilson, 1967). Such species are vulnerable to bottom-trawl fisheries and other human activities such as oil and gas exploration. Because corals and sponges grow very slowly, recovery of these habitats may require from decades to centuries to recover, and in some cases may not recover at all (Fosså et al., 2002; Fosså and Kutti, 2010). As such, they are examples of Vulnerable Marine Ecosystems (VMEs). Impact or damage may lower the local biodiversity and diminish the possibility for many species to find shelter and feeding grounds (Buhl-Mortensen, 2006).

The most widespread fishing gear used in the central Barents Sea is bottom trawl, but also long line and gillnets are used in the demersal fisheries. Pelagic fisheries use purse seine and pelagic trawl. Trawl doors may cause furrows of up to 20cm deep depending on the door weight and the hardness of the sediment. Such marks are likely to last longer in sheltered areas with fine sediments. Side-scan and video recordings of a sandy/gravel bottom in the Barents Sea also showed physical disturbance from trawling, with highly visible furrows (10cm deep and 20cm wide) and berms (10cm high) caused by the doors and smaller depressions created by the rockhopper gear (Humborstad et al., 2004; Løkkeborg, 2005).

It is estimated that between 30 and 50% of *Lophelia* reefs are either impacted or destroyed by trawling. Passive gear like long-lines and gillnets anchored on the bottom also impact the coral reefs, but to a considerably lower extent than trawling (Fosså et al., 2002). Norway's Institute of Marine Research has documented the remains of sponges left behind in bottom trawl tracks. In addition to the direct physical destruction (crushing) from bottom trawling, particles are stirred from the seabed which may block the sponges' pores; thus reducing their ability to filter food particles from the water (Buhl-Mortensen, 2006).

A comprehensive experiment conducted on the Grand Banks showed a 24 percent decrease in total biomass of megabenthic species (Prena et al., 1999). For the macrofauna, total numbers of individuals decreased by 25 percent (mainly owing to declines in polychaetes) immediately after trawling in one of the three years of the experiment (Kenchington et al., 2001). The most prominent feature of the Grand Banks study was considerable interannual variability in the mega- and macrofaunal assemblage, which indicates that the benthic community at the study site is dynamic and exhibits natural changes (Kenchington et al., 2001). Similar conclusions can be drawn from the Barents Sea experiment by Kutti et al. (2005) and Løkkeborg (2005).

2.6.3.3 Acidification (CO_2 emissions)

As an inflow shelf into the Arctic Ocean the Barents Sea has a strong potential for significant uptake of CO_2 from the atmosphere, and is vulnerable to the effect of increased levels of CO_2 leading to ocean acidification (Orr et al., 2005; Steinacher et al., 2009; Bates and Mathis, 2009). This may be detrimental to marine organisms, and hence may affect energy transfer through food-chains (Fabry et al., 2008). Several studies have demonstrated a coupling between sea-ice melt and calcification state, implying that further freshwater addition from glacier and sea-ice melt may speed up acidification (Chierici and Fransson, 2009; Yamamoto-Kawai, 2009). The increase in atmospheric CO_2 and elevated oceanic uptake of atmospheric CO_2 results in decreased pH and carbonate ion concentrations; this is expected to put stress particularly on calcifying marine organisms (i.e., calanus, pteropods, and fish). Due to its present carbonate chemistry with relatively high CO_2 levels, the Barents Sea is particularly vulnerable for enhanced freshening and loss of sea-ice cover, which will promote further solubility and amplification of ocean acidification. In addition to direct effects of changes in pH and carbonate ion concentrations on marine organisms and ecosystems, there also may be indirect effects on internal molecular processes within marine organisms (i.e., blood-regulation and protein synthesis). Additional effects include, potential changes in biogeochemical cycling of substances, especially nutrients and micronutrients, and their bioavailability for primary production (Breibarth et al., 2010; Ingvaldsen et al., 2013).

2.6.3.4 Pollution

The Barents Sea remains relatively clean with low pollution levels compared to marine areas in many other industrialized parts of the world. Major sources of contaminants in the Barents Sea include: natural processes; long-distance transport of atmospheric deposition; accidental releases from local industrial activities; and vessel fuel emissions. Norway has recently conducted a number of baseline studies to provide essential and reliable information on levels of contamination in important commercial species in the Barents Sea and adjacent waters, e.g., concentrations of metals in muscle and liver tissues of more than 800 Northeast Arctic cod caught at 32 sites during 2009-2010 (Julshamn et al., 2013).

Reported disposal of large quantities of radioactive wastes in Arctic Seas by the former Soviet Union has prompted interest in the behavior of long-lived radionuclides in polar waters. The question has arisen as to whether radionuclide bioconcentration factors and sediment partition coefficients in the Arctic are different from those derived from studies in temperate ecosystems. Fisher et al. (1999) present concentrations in seawater and calculated in situ bioconcentration factors for 90Sr, 137Cs, and 239+240Pu (the three most important radionuclides in Arctic risk assessment models) in macroalgae, crustaceans, bivalve molluscs, sea birds, and marine mammals as well as sediment Kd values for 13 radionuclides and other elements in samples taken from the Barents Sea and the Kara Sea. Results indicated that surface water concentrations of each of the three radionuclides were very similar between the two bodies of water, indicating no evidence of locally elevated concentrations of any of these contaminants in the dissolved phase. Further, surface and deep water concentrations of 90Sr and 137Cs generally did not differ appreciably (Fisher et al., 1999).

2.6.3.5 Aquaculture effects

Norwegian aquaculture has grown from its pioneering days in the 1970s to be a major industry (Taramger et al., 2014). Along with expansion have come a number of operational challenges related to: genetic integrity of wild stocks; parasitism; disease; and nutrient loading of the environment. It has even been suggested, that salmon farming may actually be the major threat to the viability of wild salmon populations due to facilitating the spread of diseases, escapees, environmental pollution, etc. (Liu et al., 2011). Based on evidence of the severity, geographical extent and duration and/or reversibility of the various impacts related to open sea cage salmon farming in Norwegian coastal waters, Taranger et al. (2014) report on a risk assessment the environmental impact of salmon farming considering hazards related to: 1) genetic introgression of escaped farmed salmon into wild populations; 2) impact of salmon lice (*Lepeophtheirus salmonis*) on wild salmonid populations; 3) potential disease transfer from farmed salmon to wild salmonid populations; and 4) local and regional impacts of nutrient loading from marine salmon farms. Primary findings were that:

- During 2010-2012, 21of the 34 populations included in assessment (62%) had moderate-to-high risk of undergoing genetic changes due to introgression of farmed salmon. However, a recent study of 20 Norwegian rivers has demonstrated that there is only a moderate correlation between the observed frequency of escapees and introgression of farmed salmon; therefore, validation of the level of introgression in a higher number of native populations will be required in the future.
- During 2010–2013, salmon lice infections from salmon farming were estimated at109 stations along the Norwegian coastline. Twenty-seven of these stations (25%) indicated moderate or high likelihood of mortality for wild migrating salmon smolts. For sea trout later in the season, 67 of the stations indicated moderate or high likelihood of mortality on wild sea trout.
- The high frequency of viral disease outbreaks in farm-raised salmon entails extensive release of causal pathogens for certain diseases in many areas. This makes it likely that migrating wild salmon and local sea trout will be exposed to the associated causal pathogens. However, the extent and consequences of this exposure remain largely unknown.
- During 2013, 2% (of the 500 stations investigated) had unacceptable organic loading in fauna and benthic sediments under fish farms. Whereas, 11% classified with high organic loading, but were still within an acceptable threshold. The remaining 87% of the farms had

a moderate-to-high loading conditions. The risk of eutrophication and organic overloading in benthic communities beyond the farm production area was considered low based upon case studies and limited monitoring data (Taramger et al., 2014).

2.6.3.6 Invasive and Non-indigenous species

Non-indigenous aquatic species are of primary concern to many regulating authorities and are seen as a top anthropogenic threat to the world's oceans. In many regions the most prominent introduction vectors are shipping, intentional introductions for aquaculture and stocking purposes — including target and non-target species. Hence, the relatively low number of non-indigenous species occurring in European Arctic waters (including the Barents Sea) may be due to the comparably lower number of ports accommodating ships during inter-oceanic voyages, and fewer aquaculture facilities (Gollasch, 2006). Nonetheless, a number of non-indigenous species — ranging from unicellular algae to vertebrates, but excluding parasites and pathogens — are reported to have established self-reproducing populations in European Arctic waters, including: wire weed/japweed/strangle weed (*Sargassum muticum*); green sea fingers (*Codium fragile*-Fragile ssp.); red alga (*Bonnemaisonia hamifera*); soft-shelled clam (*Mya arenaria*); soft clam; long-necked clam; red king crab (*Paralithodes camtschaticus*); and snow crab (*Chionoecetes opilio*) (ICES ACOM, 2009).

The 2 non-indigenous crab species currently play a significant role in both the Barents Sea ecosystem and economy:

- Red king crabs were intentionally introduced into the Barents Sea by Russian scientists more than 40 years ago and has now become a common species in coastal areas in northeastern Norway and coastal and also covers more offshore areas in Russian waters. Along the Norwegian coast the red king crab is common west of the border between Troms and Finnmark, and eastwards at the entrance to the White Sea in Russian waters. Red king crabs are fished commercially in the Barents Sea, and fishing quotas in the two countries are decided separately (Hjelset, 2014).
- Snow crabs were first recorded in 1996 at Goose Bank in the eastern region of the Barents Sea. Since then it has spread throughout the Russian sector and is now found in most of the eastern Barents Sea. Rough estimates by Russian scientist indicate that snow crab biomass is approximately ten times higher than that of red king crab, and about half the biomass of shrimp. This indicates that the snow crab is now a major component of the Barents Sea ecosystem's food web. However, the ecology of this new inhabitant is not well understood.
- Despite the potential negative effects —from accidental or intentional introductions of non-indigenous species — on the Barents Sea ecosystem, there are quite obvious positive aspects -for the economic prosperity of the region. Both red king crab and snow crab opilio have become important commercial species in the Barents Sea.
    - Red king crab has been exploited by both Russia and Norway since 1994, with a total catch of 8 – 10 thousand tons during some years. Predicted annual catch of red king crab in the coming years may be around 6-8 thousand tons.
    - During 2013, an experimental fishery for snow crabs opilio was conducted in international waters of the Barents Sea for the first time; total catch did not exceed 500

metric tons, but according to forecasts of abundance for snow crab opilio its annual catch in the coming years may be about 20-50 thousand tons. Russian authorities planned to start a small fishery for snow crab in 2014 (Hjelset, 2014).

Overall picture

The Barents Sea is a unique Arctic marine ecosystem, characterized by distinct bathymetry and bottom topography, a large oceanic shelf, an extensive polar front, high productivity, and a high abundance and diversity of flora and fauna. It is one of the shallow shelf seas surrounding the Arctic Circle which collectively form the Arctic Continental Shelf. It is situated north of Norway and north-west of Russia, and ranges over latitudes from 68 to 82°N. It is the transition and mixing zone for warm and saline water on its way from the Atlantic Ocean and the Norwegian Sea to the Arctic Ocean, and for cold and less saline water from the Arctic to the Atlantic. The majority of the drainage basin is located in Russian territory, with small parts located in Norway and Finland. As it forms the meeting point between the Atlantic and the Arctic Oceans, and Western Europe and Russia, the Barents Sea has many politicians and researchers who are interested in its biological resources, its oil and gas reserves, and the potential risks of radioactive pollution. The most pressing issues for the Barents Sea ecosystem are considered to be overexploitation of fish, the threat of oil spills, potential radionuclide contamination, and the modification of ecosystems by invasive species (UNEP, 2004). Overexploitation of fish may be the most important issue since the major commercial fish stock (cod and haddock) are exploited beyond safe biological limits. Currently, the impacts of pollution by oil spills and radioactive wastes remain slight. However, due to the expansion of the oil and gas industry in the region, and increased shipments of oil and gas through the Barents Sea, the risk of accidental oil spills is likely to increase in the near future. There are also apprehensions that storage facilities for radioactive wastes could result in radioactive contamination of the environment, as the Murmansk Region houses more radioactive wastes than any other region in the world. With respect to the modification of ecosystems, there are concerns that the invasive Red king crab will compete with native species for forage reserves, which could result in the decrease of commercial fish stocks of the Barents Sea. Another problem, linked to oil transportation, is the risk of unintentional introduction of non-indigenous species in the ballast water of oil tankers (UNEP, 2004).

Patterns of circulation in the Barents Sea are influenced by large-scale atmospheric circulation, inflow of waters from adjacent seas, bottom topography, tides, and other factors, all of which make climatic conditions rather complicated and highly variable. Three main water masses occur in the Barents Sea: the warm and saline Atlantic Waters; the fresh and cold Arctic Waters; and the Norwegian Coastal Current Waters. Characteristics of these water masses change along the pattern of currents when water from one particular origin mixes with the surrounding water. Water masses will therefore vary in different regions of the Barents Sea.

Due to the inflow of North Atlantic waters, the Barents Sea is an area of relatively high biological productivity. There is a rich and diverse community of plankton in the system, sustaining higher trophic levels. The ecosystem supports some of the world's largest stocks of cod (*Gadus morhua*), capelin (*Mallotus villosus*), and haddock (*Melanogrammus aeglefinus*), and is the main nursery ground for the large stock of Norwegian spring spawning herring (*Clupea harengus*). The Barents Sea is of great importance to fisheries, particular cod fisheries, in Norway, Russia, and a host of other countries. This ecosystem is also the home to one of the largest concentrations of seabirds in the world and a diverse assemblage of marine mammals.

At present the Barents Sea remains a relatively pristine area of the Arctic, although a large variety of man-made chemicals are found in most compartments of the marine environment. Moreover, substantial, oil and gas reserves have been discovered there; further petroleum exploration is ongoing, and extraction facilities are already in operation in both Russian (oil) and Norwegian (gas) waters. Accordingly, the challenge is to ensure that these activities can take place alongside the traditional use of the sea (fisheries) without negatively affecting the marine resource base, the environment, and consumer safety.

The Barents Sea ecosystem is driven by climate conditions and is highly susceptible to the effects of climate change, e.g., temperature, which strongly influences the distribution, growth, recruitment, and productivity of species which support major international fisheries. Human effects on climate include those caused by increased release of greenhouse gases into the atmosphere creating a small but steady temperature increase each year. Accumulated over many years, significant change occurs particularly in the Arctic where the rate of temperature increase is double the global average. Albeit, climate change arises from both natural and anthropogenic (human-induced) causes, the effects of anthropogenic climate change in the Barents Sea are already apparent. Examples include: a general warming trend since the 1970s; a large reduction in winter ice coverage — annual sea ice extent has decreased by 50%, reaching its lowest level for the last 60 years (Årthun et al., 2012); and increased precipitation and fresh-water runoff.

Although climate change affects organisms inhabiting the Barents Sea ecosystem in direct and profound ways, the mechanism through which this occurs are not well understood. It remains difficult to predict what effects climate change will have upon life in the Barents Sea.

Release of greenhouse gas (CO_2) emissions into the atmosphere is also linked to ocean acidification — another emerging issue in the Barents Sea. The primary driver of this acidification is the ocean's slow absorption of CO_2. This ocean uptake of CO_2 slows its build-up in the atmosphere and the pace of human-induced climate warming, but at the same time increasing seawater acidity. As a result of this process, the average acidity of surface ocean waters worldwide is now about 30 percent higher than at the start of the Industrial Revolution. Since the late 1960s, decreases in seawater pH of about 0.02 per decade have been observed in the Barents Sea. While it is likely that some marine organisms will respond positively to more acidic conditions, others will be disadvantaged, possibly to the point of local extinction: pteropods (sea butterflies) and echinoderms (sea stars, urchins) are important organisms in the Barents Sea food web which may be sensitive to ocean acidification.

A number of human pressures combine with climate variability to determine the environmental status of the Barents Sea ecosystem, including: fisheries; activities related to petroleum (oil and gas) exploration and extraction; transport of cargo through shipping; tourism; aquaculture; and bioprospecting. Perhaps the effects of human-induced climate change and ocean acidification in combination with the potential effects of overfishing and escalating oil and gas activities are the greatest threats to sustainable productivity.

Careful monitoring of essential components of the Barents Sea ecosystem and conducting integrated ecosystem assessments are important tools for effective research and management of its of its natural and mineral resources.

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3 Monitoring the ecosystem

J.E. Stiansen (IMR), A.A. Filin (PINRO), M.M. McBride (IMR), K. Nedreaas (IMR), K.M. Kovacs (NPI), A.L. Karsakov (PINRO), C.D. Olseng, and H. Strøm (NPI)

3.1 Introduction

To ensure the comparability of monitoring data and to estimate seasonal and year-to-year variations in oceanographic variables, it was suggested in Stockholm as early as 1899 that measurements should be taken at standard depths in standard spatial areas (sections). At the beginning of the 20th century, a monitoring program was initiated in the Kola Section of the Barents Sea (Knipovich 1906), and by the 1930s, a monitoring network had been developed in this area (Figure 3.2.1).

During the last 50 years regular monitoring of ecosystem components in the Barents Sea have been conducted both at sections and by area covering surveys from ships and airplanes. In addition, many long- and short-term special investigations — designed to study specific processes or knowledge gaps — have been conducted. Also, the quality of large hydrodynamic numeric models has reached a level which makes them useful to fill information gaps in time and space for some parameters. Satellite data and hind-cast global reanalysed datasets are also useful information sources.

Old "G.O. Sars" and "Vilnius" under an intercalibration run of acoustic equipment.

Monitoring systems for ecosystem dynamics and human activities within the Barents Sea are based on existing time series of data collected by a number of Norwegian and Russian institutes. Contributions from different institutes to this monitoring effort are reflected in Tables 3.1.1-3.1.2.

Table 3.1.1. Contributions by different institutes to monitoring of the Barents Sea ecosystem (++ large effort, + some effort, - no effort).

Institute's abbreviation*	**Ecosystem components**						
	Climate	**Phytoplankton**	**Zooplankton**	**Benthos**	**Fish and shellfish**	**Mammals**	**Seabirds**
Norwegian							
ADB	-	-	-	-	-	-	-
Akvaplan-niva	+	-	-	++	+	-	-
Biofosk	-	-	-	-	-	-	-
DN	-	-	-	++	-	-	++
FDir	-	-	-	-	-	-	-
IMR	++	++	++	++	++	++	-
KV	-	-	-	-	-	-	-
MI	++	-	-	-	-	-	-
NILU	++	-	-	-	-	-	-
NINA	-	-	-	-	++ (salmon)	+ (sea otter)	++
NIVA							
NPI	++	+	++	+	+	++	++
NVH							
OD/NPD	-	-	-	-	-	-	-
SFT	-	-	-	-	-	-	-
SSV/NRPA	-	-	-	-	-	-	-
VI	-	-	-	-	-	+	+

Russian							
PINRO	++	+	+	++	++	++	+
MMBI	++	++	++	+	+	++	++
SMG	+	-	-	-	-	-	-
AARI	+	-	-	-	-	-	++
VNIIOceangeology	+	-	-	-	-	-	-
VNIIPriroda	-	-	-	-	-	++	-

Monitoring methods are often developed for one or several target species or ecosystem variables (e.g. temperature and salinity). Full use of various monitoring platform is essential to build up as broad a knowledge base as possible of ecosystem structure and variability. Therefore, monitoring programs are designed and conducted as broadly as possible to serve multiple uses. However, it is impossible to monitor all species (e.g. ~3000 species of benthos, ~200 species of fish, ~25 species of marine mammals, etc). Therefore, biological monitoring has historically been focused on the key species of commercial importance. In recent years, however, greater focus has been placed on species diversity and trophic interactions.

During the course of a year, a single ecosystem component (e.g., zooplankton) may be monitored using multiple measurement designs or platforms (e.g., transects, random surveys, fixed stations, etc). Therefore this chapter is basically divided into two parts. The first part describes monitoring "platforms", in a broad sense (Chapter 3.2). The second part describes monitoring from the perspective of a single ecosystem component (Chapter 3.3).

It should be noted that even though institutions contributing to this report are responsible for most ecosystem monitoring conducted in the Barents Sea, other groups also are engaged in environmental monitoring in this region. This report basically focuses on monitoring programs conducted by contributing institutions.

Table 3.1.2. Contribution of different institutes to monitoring of the human activities in the Barents Sea and its impact on the ecosystem, related to the content of this report. (++ large effort, + some effort, - no effort)

Institute abbreviation*	**Human activities and its impact**						
	Fisheries	**Oil and gas**	**Pollution**	**Aquaculture**	**Shipping**	**Other activities**	**Threatened species**
Norwegian							
ADB	-	-	-	-	-	-	-
Akvaplan-niva	-	++	++	++	+	++	+
Biofosk	-	++	++	-	++	-	-
DN	-	-	-	-	-	+	-
FDir	+	-	-	+	-	-	-
IMR	++	++	++	+	-	++	+
KV	-	-	+	-	++	-	-
MI	-	++	++	-	-	-	-
NILU	-	-	++	-	-	-	-
NINA	+	+	+	+	+	-	++
NIVA							

NPI	-	-	++	-	-	-	+
NVH							-
OD/NPD	-	-	-	-	-	-	-
SFT	-	-	++	-	-	-	-
SSV/NRPA	-	-	++	-	-	-	-
VI	-	-	+	-	-	-	-
Russian							
PINRO	++	++	++	++	-	-	+
MMBI	+	+	++	+	+	-	++
SMG	-	++	++	-	+	-	-
AARI	-	-	-	-	+	-	++
VNIIOceangeology	-	+	+	-	+	-	-
VNIIPriroda	-	+	+	-	-	-	++

3.2 Monitoring platforms

3.2.1 Standard sections and fixed stations

At the beginning of the 20th Century, monitoring — of temperature, salinity, nutrients, and chlorophyll a — was initiated in the Kola Section of the Barents Sea (Knipovich 1906); by the 1930s, a network of standard transects had been developed in this section (Figure 3.2.1). During the last decades, zooplankton has also been sampled. An overview of the sampling time period, frequency of observations, and variables measured for the standard transects is given in Table 3.2.1. Specific considerations for the most important sections are given in the following text.

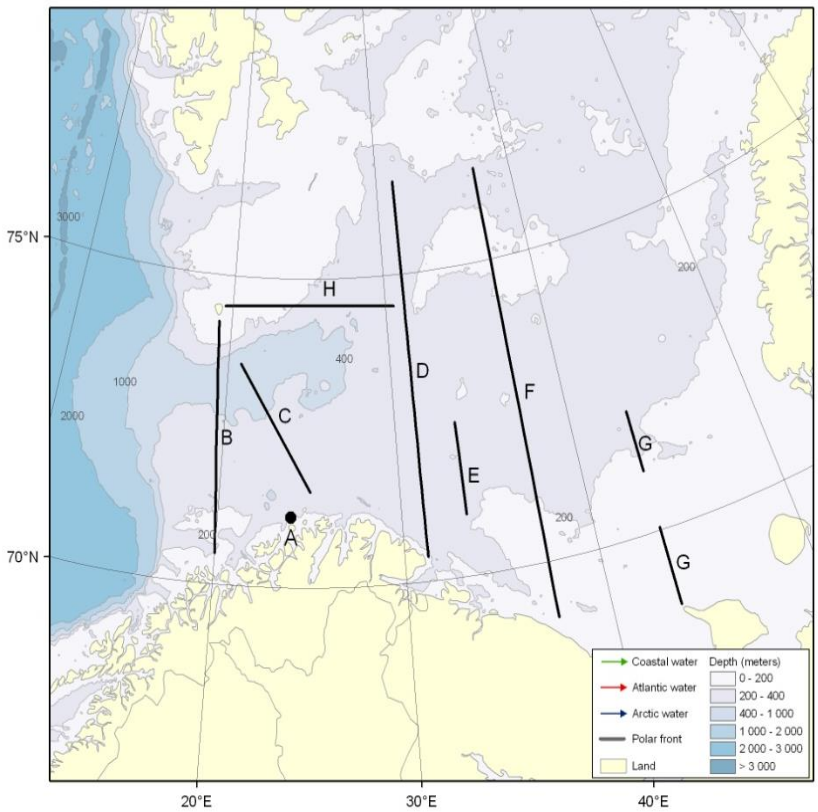

Figure 3.2.1. Positions of the standard sections monitored in the Barents Sea:

A is fixed station Ingøy;

B is Fugløya-BearIsland;

C is North Cape-Bear Island;

D is Vardø-North;

E is Kola;

F is Sem Island-North;

G is Kanin section; and

Table 3.2.1. Overview of the standard sections monitored by IMR and PINRO in the Barents Sea, with observed parameters. Parameters are: T-temperature, S-Salinity, N-nutrients, Chla-chlorophyll a, Zoo-zooplankton.

Section	Institution	Time period	Observation frequency	Parameters
Fugløya-Bear Island	IMR	1977 - present	4-6 times/year*	T, S, N, Chla, Zoo
North Cape-Bear Island	PINRO	1929 - present	1-2 times/year	T, S
Bear Island-East	PINRO	1936 - present	1-2 times/year	T, S
Vardø-North	IMR	1977 - present	4 times/year**	T, S, N, Chla
Kola	PINRO	1900 - present	12 times/year	T, S, O, N, Zoo
Kanin	PINRO	1936 - present	1-2 times/year	T, S
Sem Islands	IMR	1977 - present	Intermittently***	T, S

* Taken once per year back to 1953
** Taken once per year back to 1964
*** The Sem Island section is not observed each year

The Fugløya-Bear Island section is situated at the western entrance to the Barents Sea, where the inflow of Atlantic water from the Norwegian Sea takes place. This section is representative for the western part of the Barents Sea. It has been monitored regularly since August 1964, and observation frequency increased to 6 times per year in 1977. Zooplankton monitoring began in 1987, and monitoring of phytoplankton (algae) in 2005.

Monitoring of the North Cape-Bear Island section has been conducted since 1929, and crosses the main branch of the North Cape Current. In the 1960s, the section was sampled up to 26 times a year. In recent years it has been sampled on a quarterly basis.

Monitoring of hydrographic conditions in the section east of the Bear Island (along 74°30’N) has been carried out since 1936. It crosses the northern branch of the North Cape Current and cold waters of the Bear Island Current. It is sampled 1-2 times a year and characterises thermohaline parameters of the Atlantic waters flowing into the northern Barents Sea.

The Vardø-N section has been monitored in August regularly since 1953, and sampling frequency increased to 4 times per year in 1977. Situated in the central Barents Sea, it is most representative for the Atlantic branch going into Hopen Trench, i.e. the central Barents Sea. The northern part of the sections is usually in Arctic water masses. Zooplankton monitoring in this section began in 1994, and monitoring of phytoplankton (algae) from 2005.

The Kola section is situated partly in both coastal- and Atlantic water masses, and is the section that best represents the Atlantic branch going eastwards parallel to the coastline, i.e. the southern Barents Sea. Some gaps in data time series exist, but sampling in this section has generally been quite regular. Time series of quarterly temperature sampling data are available from 1900-present, and of monthly sampling from 1921-present.

Monitoring in the Kanin section has been conducted since 1936; it includes the Kanin Current and the main branch of the Murman Current, as well as the fresher waters of the White Sea Current, which flow into the Barents Sea from the opening of the White Sea. The section is now sampled 1-2 times a year.

Monitoring of the Sem Island section has been conducted intermittently since 1977. During the period 1977-1995, the section was sampled regularly 2 times a year. In later years it has been sampled only a few times, with the latest observations made in 2000.

IMR samples a series of fixed stations along the Norwegian coast. However, only one fixed station, Ingøy, is connected to the Barents Sea. The Ingøy station is situated within waters of the Norwegian Coastal Current along the Norwegian coast. Temperature and salinity are monitored 1-4 times a month. Samples were obtained within two periods, 1936-1944 and 1968-present.

3.2.2 Surveys

Aerial surveys are conducted throughout the year. The number of vessels deployed may differ between surveys and also from year to year. Most surveys are conducted using only one vessel. It is not possible to measure all ecosystem components during a single survey. Additionally, investigations must use time efficiently, and focus on a definite set of parameters/species to give a synoptic picture of ecosystem conditions. Therefore, some parameters measured may not receive optimal sampling coverage. As result, considerable uncertainty may be associated with information on the latter, even though the information is valuable. Table 3.2.2 presents an overview of parameters and species measured during major surveys.

3.2.2.1 Norwegian/Russian winter survey

This survey is carried out during February-early March, and covers the main cod distribution areas in the Barents Sea. During some years coverage is limited by the ice distribution. Three vessels are normally deployed, two Norwegian and one Russian. The main observations are made with bottom trawl, pelagic trawl, echo sounder and CTD. Plankton studies have been done in some years. Cod and haddock are the main species targeted in this survey. Swept area indices are calculated for cod, haddock, Greenland halibut, redfish (*Sebastes Marinus*) and deepwater redfish (*S. Mentella*). Acoustic observations are made for cod, haddock, capelin, redfish, polar cod, and herring. The survey was initiated in 1981.

3.2.2.2 Lofoten survey

The main spawning grounds for North East Arctic cod are in the Lofoten area. Echosounder equipment was first used in 1935 to detect concentrations of spawning cod, and the first attempt to map such concentrations was made in 1938 (Sund, 1938). Later investigations have provided valuable information on the migratory patterns, the geographical distribution and the age composition and abundance of the stock.

The time series of survey data extends from 1985 to present. Due to changes in echo sounder equipment in 1990, results obtained before 1985 are not directly comparable with later results. The survey is designed as equidistant parallel acoustic transects covering 3 strata (North, South, and Vestfjorden). In most surveys prior to 1990, transects were not parallel, but rather formed a zigzag pattern across the spawning grounds to map cod distribution. For practical reasons, i.e., obstructions caused by fixed commercial fishing gear, trawl samples are not taken according to a stratified random survey design; rather, samples must be taken more opportunistically. Spawning concentrations can be located through echo sounding which effectively reduce the number of trawl stations needed. The ability to properly sample stock composition (age, sex, maturity, etc.) is limited by the amount of fixed commercial gear (gillnets and longlines) in different areas.

Table 3.2.2. Overview of monitoring surveys conducted by IMR and PINRO in the Barents Sea, with observed parameters and species. Species in bold are target species. Abundance, biomass, and distribution for many species — zooplankton, mammals, and benthos — are investigated. The table indicates whether sampling is conducted or not. Parameters measured are: T-temperature, S-Salinity, N-nutrients, Chla-chlorophyll.

Survey	Institution	Period	Climate	Phytoplankton	Zooplankton	Juvenile fish	Target fish stocks	Mammals	Benthos
Norwegian/Russian winter survey	Joint	Feb-Mar	T, S	N, Chla	Intermittent	All commercial species and some additional	Cod, haddock	-	-
Lofoten survey	IMR	Mar-Apr	T, S	-	-	-	Cod, haddock, saithe	-	-
Ecosystem survey	Joint	Aug-Oct	T, S	N, Chla	Yes	All commercial species and some additional	All commercial species and some additional	Yes	Yes
Norwegian coastal survey	IMR	Oct-Nov	T, S	-	Yes	Herring, sprat, demersal species	Saithe, coastal cod	-	-
Autumn-winter trawl-acoustic survey	PINRO	Oct-Des	T, S	N, Chla	Yes	Demersal species	Demersal species	-	-
Russian young herring survey	PINRO	May	T, S	-	Yes	Pelagic species	Herring	-	-
Norwegian Greenland halibut survey	IMR	Aug	-	-	-	-	Greenland halibut, redfish	-	-

3.2.2.3 Norwegian coastal survey

During 1985-2002, a Norwegian acoustic survey, specially designed for saithe, was conducted annually during October-November (Nedreaas, 1998). This survey covered near coastal banks extending from Varangerfjord close to the Russian border southwards to 62°N. The entire area has been covered since 1992, and major portions of the entire area since 1988. This acoustic survey targeting Northeast Arctic saithe was conducted to provide fishery-independent data on the abundance of young saithe for stock assessment. The survey mainly covered grounds where the trawl fishery takes place, normally dominated by 3 - 5(6) year-old fish. Two-year-old saithe — mainly inhabiting the fjords and coastal areas — were also taken in the survey, but sampling was highly variable from year to year. During 1995-2002, a Norwegian acoustic survey — mainly for coastal cod — was conducted along coastal and fjord areas from Varanger to Stad. This survey took place in September, just prior to the saithe survey described above, and covered coastal areas not included in the regular saithe survey. In autumn 2003, the saithe- and coastal cod surveys were combined; the survey design was improved and expanded to also cover 0-group herring in fjords north of Lofoten.

3.2.2.4 Joint Norwegian/Russian ecosystem survey

This survey is carried out each year during autumn (from early August to October), and covers the entire Barents Sea. Four to five vessels are normally deployed, three Norwegian and one or two Russian. Most components of the ecosystem are covered: physical and chemical oceanography; plankton; benthos; fish (both juvenile and adult stages); shellfish; marine mammals; and seabirds. A number of different sampling methods and gear types are used, including: water samples; plankton nets; pelagic and demersal trawls; grabs; and sledges; acoustics; and direct visual observations of birds and marine mammals. This survey has gradually evolved from joint surveys initiated in 1972 on 0 age-group capelin and Greenland halibut using general acoustic methods and samples to measure physical oceanography and plankton into the more comprehensive ecosystem survey carried out since 2003. In association with this survey, Russia also covers parts of the Northern Kara Sea, and IMR covers the shelf east and north of Svalbard.

3.2.2.5 Russian autumn-winter trawl-acoustic survey

This survey is carried out during October-December, and covers the Barents Sea up to the continental slope. Two Russian vessels are usually deployed. The survey has developed from a young cod and haddock trawl survey initiated in 1946. The current trawl-acoustic time series of survey data begins in 1982, and includes both juvenile and adult stages of bottom fish species. The survey also monitors physical oceanography, mesozooplankton, and macro-zooplankton.

3.2.2.6 Russian young herring survey

This survey is conducted over 2-3 weeks during May. It also monitors physical oceanography and plankton. During 1991-1995, it was a joint survey; since 1996, the survey has been carried out only by PINRO.

3.2.2.7 Norwegian Greenland halibut survey

This survey is carried out during August, and cover the continental slope from 68 to 80ºN, at depths of 400–1500 meters north of 70º30'N, and 400–1000 meters south of this latitude. This survey was initiated in 1994, and is now part of the Norwegian Combined survey index for Greenland halibut. This survey was not conducted in 2010, and has been conducted biennially since 2011.

3.2.3 Hydrodynamical numerical models and ecosystem models

Large 3D hydrodynamic numeric models for the Barents Sea have been validated through observations, and have been useful for filling observation gaps in time and space. These models estimate temperature, salinity, ice, and circulation conditions in the ocean. The models have also proven useful for scenario testing, and to study drift patterns of various planktonic organisms. These models are developed and utilized at several Norwegian and Russian institutions, at different scales and resolutions.

Other ecosystem models are under development. These models will simulate the major ecosystem functioning and energy transfer in the food web. Models such as NORWECOM.E2E (Hjøllo *et al*., 2012) and Atlantis (Fulton *et al*., 2004) are semi-operational, and others like Ecopath are used for targeted investigations. Such models may also be used to fill information gaps in time and space which are not covered by observations. Both hydrodynamic and ecosystem models run on an operational basis, i.e., regular updates, are useful to supplement observation-based monitoring systems. The prerequisite is that they are well documented and validated through observations with reasonable confidence. Future monitoring systems may utilize the combined strength of observations and models; this offers huge to improve surveillance of the ecosystem.

3.2.4 Other information sources

Satellites can be useful for several monitoring tasks. Ocean colour spectre can be used to identify and estimate the amount of phytoplankton at the surface (~1 m) layer. Several climate variables can also be monitored (e.g. ice cover, cloud cover, heat radiation, sea surface temperature). Marine mammals, polar bears, and seabirds can be traced with attached transmitters.

Aircraft surveys can also be used to monitor several physical parameters associated with the sea surface, to observe marine mammals at the surface, and to estimate harp seal pup production in the White Sea.

Along the Norwegian coast, ships-of-opportunity provide weekly sea surface temperature measurements along the path of their journey.

Tagging fish and marine mammals has been used for many years to track their horizontal migration and vertical movements. Historically the tags have only provided information about starting location and recapture location, but now electronic markers can monitor several parameters, i.e., geographic coordinates (position through satellite signals when at surface), in situ temperature, and salinity.

3.2.5 Databases

Databases are not monitoring, but they serve as important "platforms" facilitating further work and analyses of the data collected. Many databases have been developed for the Barents Sea ecosystem, but few are linked and many are difficult to access without a high level of expertise. However, work is ongoing toward both higher accessibility and to establish better linkages between databases.

Of particular relevance for ecosystem studies, both the newly developed aggregated ecosystem database BARMAR (Barents Sea Marine Atlas), and the fish stomach contents databases at IMR and PINRO — containing results of approximately 380 thousand stomachs examined by the end of 2006 (Dolgov et al., 2007)) —should be mentioned.

Several international hindcast databases are available (including parameters such as sea surface temperatures, sea surface salinity, ice cover, etc), as well as data from the large climate change models (Randall et al., 2007). They use a combination of numerical models and available observations to estimate a number of climate variables globally.

3.3 Monitoring divided of ecosystem components and human activities

3.3.1 Climate monitoring

To evaluate the state of the physical environment, several sources of information are used. Area surveys of temperature and salinity are conducted in January-February during the joint winter survey, and in August-October during the joint ecosystem survey. The standard sections also form an important base to evaluate temperature and salinity. In particular, seasonal changes are monitored at the Kola and Fugløya-Bear Island sections, and at the fixed station in Ingøy. In the Fugløya-Bear Island section, a series of current meter monitors provide high resolution flow measurements through the western entrance of the Barents Sea. In addition, hydrodynamic numeric models provide insight into horizontal and vertical temperature variation, water masses distribution, and water transport. Satellite data also provide sea surface temperature, salinity, ice cover measurements.

3.3.2 Phytoplankton monitoring

Figure 3.3.1 and 3.3.2 indicate months during which phytoplankton species and cell numbers were sampled by Norwegian ships at the Fulgløya-Bjørnøya (FB) and Vardø-Nord (VN) transects, and the spread (within these months) of sampling date during the period 2004-2012. For operational reasons, sampling time and effort are not entirely uniform in all years, which limit the ability to detect changes in species composition and diversity over time; this is particularly important during spring and summer. Combined with the considerable patchiness in distribution of phytoplankton, and occurrence of mono-specific "blooms" this makes detection of any changes in species composition very difficult during the short time period for which data are available.

These surveys measure chlorophyll concentration at standard depths down to 100 m. Species composition and abundance have been determined since 2005 from water samples.

Murmansk Marine Biological Institute (MMBI) conducts cruises in eastern regions of the Barents Sea, sampling chlorophyll, and phytoplankton species composition and abundance at standard depths. In addition, color satellite data indicate phytoplankton bloom dynamics.

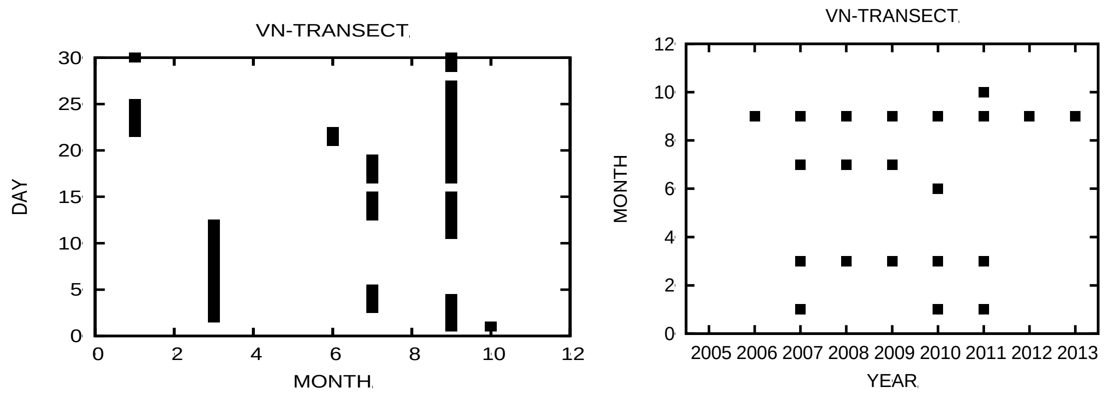

Figure 3.3.1. Sampling times and effort during the period 2004-2013 for the VN transect.

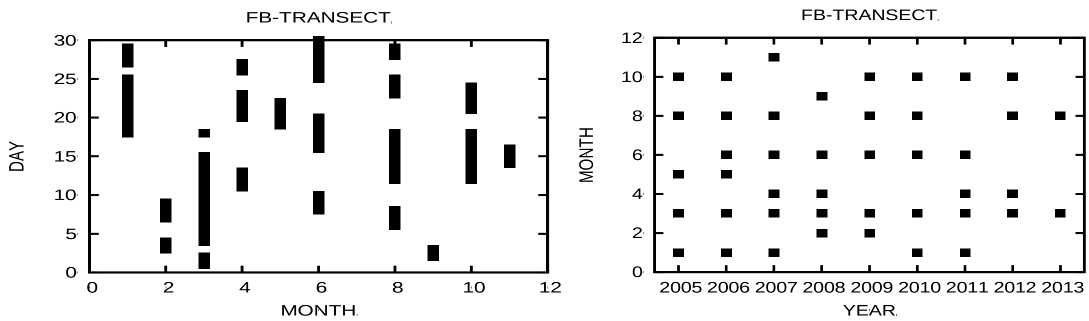

Figure 3.3.2. As for Figure 3.3.1 but for the FB transect.

3.3.3 Zooplankton monitoring

Zooplankton biomass and species distribution are monitored during the joint autumn ecosystem survey; these investigations have taken place since 2002. Regular sampling by IMR began in 1979; while PINRO conducted surveys from 1982 through 1993. A Juday net (37 cm in diameter, 180 μm) was used to obtain zooplankton samples by PINRO. IMR uses a WP2 net (56 cm in diameter, 180 μm) and a 1 m^2 MOCNESS multiple plankton trawl with 9 nets, all with 180 μm mesh size, as standard zooplankton gear. The MOCNESS is mainly used to obtain better data on vertical distribution of mesozooplankton and the gear is also somewhat more efficient for larger zooplankton components like arrow worms, euphausiids, and hyperiids. However, for some years now the Norwegian macroplankton trawl has been used in predetermined regions of Norwegian zone of the Barents Sea. The sampling approach has been to conduct double oblique hauls, from surface to near the bottom both on R/V G.O. Sars and R/V Johan Hjort. The aim has been to obtain integrated samples of macroplankton like euphausiids and hyperiids for improved assessment of their population structure. The macroplankton trawl is a fine-meshed plankton trawl with an approximate 38 m^2 mouth-opening and 3 mm stretched meshes from the trawl-opening to the rear end (see Melle et al., 2006; Wenneck et al., 2008; Krafft et al., 2010; Heino et al., 2011). Towing speed is normally 2.5–3.0 knots.

During 2005, comparisons were made between Juday and WP2 net catches from the joint autumn cruise with regard to both biomass and species composition. Biomass estimates obtained using the two gear types were quite similar. A report on of this study was prepared at a joint meeting held at IMR in May 2006, and the EcoNorth symposium in Tromsø in March 2007. During the Joint Ecosystem Survey in 2007, a specially designed double-net system — towing the Norwegian WP2 net and the Russian Juday net side by side at selected stations — was used to compare sampling efficiency of the two nets for various mesozooplankton components. A total of 19 hauls were conducted with the double-net system; all with a vertical speed of 0.5 m s^{-1} from RV G.O. Sars. A special workshop was arranged in Bergen (22-26 October 2007) where Russian and Norwegian specialists analysed most of the samples for species composition, biomass, and abundance. During the 2013 Ecosystem Survey, an additional set of data from the WP2/Juday dual net system was obtained. This time a total of 40 WP2+Juday dual net hauls were conducted between 19-20 August , half of them during night time and half during day. One aim of this exercise was to compare gear sampling performance when haul retrieval speed was increased from 0.5 to 1 m s^{-1}. Preliminary results from the 2007 gear comparison with19 hauls have been obtained, but with the new 2013 data a more thorough analysis of the dual-net comparisons will be completed.

Monitoring mesozooplankton along the Fugløya-Bear Island section was initiated by IMR in 1987, and is now conducted 5-6 times each year usually in January, March/April, May/June, July/August, and September/October. In addition, the Vardø-N section and its extended part are currently sampled 2 times each year (March/April and August/September). However, data prior to 1994 are scarce and do not represent full seasonal coverage. The WP2 plankton net has been used regularly since 1987, and vertically stratified MOCNESS tows are taken during the Joint Ecosystem Survey during August-September each year, approximately one haul each day.

Monitoring of mesozooplankton along the Kola Meridian transect was conducted by PINRO during 1959-1993 as part of the ichthyoplankton survey. In 2008, sampling was resumed and mesozooplankton samples are taken once a year (at the end of May-early June) at three layers of the water column: 0-50 m, 50-100 m, and 100 m-to the bottom. The Juday net is the main sampling gear used.

Macroplankton surveys in the Barents Sea have been conducted regularly by PINRO since 1952. Surveys involve annual monitoring of total euphausiid abundance and distribution during the autumn-winter trawl-acoustic survey. Macroplankton are collected using a net attached to a trawl (trawl net) with 0.2 m^2 opening area and 564-µm mesh size. This net is a modification of the IKS-80 egg net and is attached to the headline of a bottom trawl to catch plankton near the bottom. During winter, crustaceans are concentrated in the near-bottom layer and have no pronounced daily migrations, and consumption by fish is minimal.

Therefore, sampling euphausiids during the autumn-winter survey is used to estimate year-to-year variations in their abundance in the Barents Sea. Annually, 200-300 macroplankton samples are collected during this survey, and both species and size composition of euphausiids are determined. It is noteworthy that in spite of quite a large mesh size, the net catches both small and large organisms (Orlova et al., 2004a, b).

Gelatinous zooplankton (ctenophores and cnidarians) are caught in both the WP2 net and the MOCNESS plankton trawl. However, the degree to which catches are truly quantitative remains a question, particularly for the larger ctenophores and scyphozoans. In addition, many species are damaged in nets. Thus, estimates of their abundance can be severely biased. Since larger cnidarians of the class Scyphozoa are also caught in the pelagic Harstad trawl used for 0-group fish and capelin, this report presents catches from this trawl; however, caution should be exercised in their quantitative interpretation.

3.3.4 Benthic monitoring

Yearly monitoring of shrimps and the benthos community is conducted during autumn as part of the Joint Ecosystem Survey. This benthic mapping survey was initiated by PINRO in the early 1930's, continued in the 1960's, and then resumed in 2000. In addition to long-term monitoring programmes in the Barents Sea, basic mapping of the benthic organisms and habitat is carried out by the MAREANO project, which also maps shelf areas of the Barents Sea; plans are to expand mapping from the southern Barents Sea northward within the Norwegian zone.

Since 1982, annual trawl surveys have been conducted to gather information on shrimp stock biomass and demographic composition for the assessment. From 2004, the ecosystem survey was expanded to also include king crab, snow crab, and all other benthic species caught in the trawl.

Analysing the Campelen trawl invertebrate by-catch is a time and cost effective method that was easily implemented in the Joint Ecosystem Survey. Since 2005, Russian and Norwegian benthic scientists have developed routines to secure standardised methods on both Russian and Norwegian ships. These methods require further development, and need to be verified with quantitative benthic sampling tools to validate the Campelen trawl as a benthic sampling tool.

In addition to collecting data on red king crabs during from the Joint Ecosystem Survey, joint red king crab monitoring surveys have been carried out in the southern coastal Barents Sea each year. Information on king crab stock size and life stages is collected during these surveys. These surveys also provide the main data source for stock assessment

The snow crab population has had a large increase in recent years. A monitoring programme for this species is under development.

To ensure a method that follows benthic fluctuations in the Barents Sea, long-term monitoring areas have been established. These areas were selected using criteria such as time and cost effectiveness, human impacts, natural variation, and geographical variation (Table 3.3.1).

Table 3.3.1. Monitoring areas in the Barents Sea for monitoring of the changes in benthos under influences of different anthropogenic and environmental factors

	Factors Area	Fishery	Climate	Oil and gas exploitation	Introduced species
1	Western slope	+	+		
2	North Cape Bank		+	+	
3	Murmansk coast	+	+		+
4	Goose Bank	+	+		+
5	Shtokman field		+	+	
6	Hopen deep	+	+		

Benthic monitoring on Shtokman field and the Kola section has been carried out by MMBI. For the Kola section, the data time series dates back to 1930s. On the Shtokman field, monitoring has been conducted since 2002.

3.3.5 Fish monitoring

Most of the surveys mentioned above have monitoring commercial fish species as their main objectives. Different fish stocks at different life stages are targeted during these surveys. In addition to catch data, these surveys are the main data source for stock assessments. Data on non-target fish species (abundance, weight, length distribution, etc.) have also been collected during these surveys over the last ten years. Additional sources of information include biological data collected by Russian observers onboard commercial fishing vessels and a number of commercial fishing vessels with special reporting requirements serve as reference vessels (Figure 3.3.5).

3.3.6 Marine mammal monitoring

Most of the marine mammal monitoring activity is focussed on either commercially important species or threatened species.

Different methods are used to estimate abundance of commercially important marine mammal species in the Barents Sea. Mark-recapture experiments have been conducted to determine the abundance of harp seals since the mid 1980s (e.g. Øien and Øritsland, 1995). More recently, the preferred method to estimate abundance of ice-breeding seals and pelagic cetaceans has been strip transect-surveys conducted using aircraft for seals and using ships for whales. Øritsland and Øien (1995) attempted to survey the West Ice in 1990/1991, but weather and ice conditions prevented a complete estimate. Since that time, aerial surveys have been conducted routinely in the West Ice (Haug et al., 2006), as the International Council for the Exploration of the Sea (ICES) requires that quotas for harvesting marine mammal species commercially be based on estimates which are less than 5-years old.

The first aerial surveys for harp seals in the White Sea were conducted by Russia during 1927-28 at the time of moulting (Shafikov, 2008). Breeding surveys to estimate pup production in the White Sea were conducted in 1998, 2000, 2002, 2003, 2004, 2005, 2008, and 2009 (Potelov et al., 2003), and aerial moulting surveys of harp seals were conducted in 2001, 2002, and 2004 (Chernook et al., 2008). Compared to harp seals, hooded seals in the West Ice have received little monitoring attention, despite considerable levels of harvesting following the Second World War. The first successful aerial survey for hooded seals took place in 1997. Surveys were also conducted during 2005 and 2007 (Salberg et al. 2008, ICES 2008). Regular monitoring surveys using sighting vessels are conducted by IMR targeting minke whales and other large baleen whales. These surveys are conducted annually, so that abundance can be estimated for the overall region approximately every 6 years (Skaug et al., 2004).

Since 2002, distribution patterns of marine mammals in the Barents Sea have been observed from research vessels during the Joint Norwegian/Russian ecosystem survey. In addition, observations from aircraft, fishing vessels, and coastguard vessels are used to examine temporal and geographic distribution of selected marine mammal species. Since 2002, the programme Monitoring of Svalbard and Jan Mayen (MOSJ) has documented sightings from scientific field parties and tourist operators in the Svalbard region on an annual basis, with particular focus on white whales, narwhal, and bowhead whales. Additionally, aerial surveys are conducted within MOSJ to determine the abundance of polar bears every 10 years, and walruses every 5 years. On the coast of mainland Norway, harbour seals and grey seals are also monitored every 5 years (Nilssen and Haug, 2007; Nilssen et al., 2009).

3.3.7 Seabird monitoring

H. Strøm (NPI), J.V. Krasnov (MMBI). S. Descamps (NPI), M.V. Gavrilo (AARI), P. Fauchald (NINA), G.H. Systad (NINA) and G. Tertitski (RAS)

Overall goals of the seabird monitoring program are to evaluate the status and trends of seabird populations in relation to anthropogenic and natural environmental factors (Anker-Nilssen et al., 1996). Species and sites monitored on Russian and Norwegian sides are summarised in Table 3.3.2. A map showing location of the monitoring sites can be seen on the Russian-Norwegian environmental web portal (http://barentsportal.com).

Table 3.3.2. Seabird species and sites monitored in the Barents Sea Region.

Locality	Northern fulmar	Northern gannet	Great cormorant	European shag	Common eider	Great skua	Gulls/terns	Black-legged kittiwake	Razorbill	Common guillemot	Brünnich's guillemot	Atlantic Puffin	Black guillemot	Little auk
Spitsbergen	•				•			•			•			•
Bjørnøya	•	•				•	•	•		•	•			•
Dovorovaya Bay								•		•	•			
Seven Island		•	•	•	•	•	•	•		•	•	•		
Cape Krutic								•		•	•			
Cape Gorodetski								•		•	•			
Aynov Island				•	•	•	•					•		
Onega Bay			•		•		•		•				•	
Kandalaksha Bay			•		•		•		•				•	
Hornøy								•		•		•		
Varngerfjorden					•									
Kongsfjord/Syltefj.		•	•											
Vest-Finnmark			•	•										
Hjelmsøy/Gjesvær	•	•				•	•	•	•	•	•	•		
Troms					•									
Anda								•				•		
Vesterålen		•	•											
Røst	•		•	•		•		•	•	•		•	•	

3.3.7.1 Norwegian zone

The seabird monitoring programme for Svalbard was initiated in 1988 (Mehlum & Bakken 1994), and eight species are currently (2015) included in the programme: northern fulmar (*Fulmarus glacialis*); common eider (*Somateria mollissima*); northern gannet (*Morus bassanus*); great skua (*Catharacta skua*); glaucous gull (*Larus glaucous*); black-legged kittiwake (*Rissa tridactyla*); common guillemot (*Uria aalge*); Brünnich's guillemot (*Uria lomvia*); and little auk (*Alle alle*) (Strøm, 2006). Monitoring population trends is carried out annually for all species except little auk. Data on survival, breeding success, and chick diet are collected on Bjørnøya for all species except northern fulmar; on Spitsbergen for black-legged kittiwake, Brünnich's guillemot, and little auk (Strøm, 2006). The seabird monitoring programme at Svalbard is organized by the Norwegian Polar Institute, and data stored in the Institute's Seabird Colony Database – COLONY (Bakken, 2000).

The national monitoring programme for seabirds — established in 1988 and revised in 1996 — addresses population dynamics in 18 species of breeding seabirds along the coast, including the three key species (Atlantic puffin, black-legged kittiwake, and common guillemot) and six key sites (Runde, Sklinna, Røst, Anda, Hjelmsøya, and Hornøya) (Røv et al., 1984; Anker-Nilssen et al., 1996; Lorentsen et al., 2009). In 2005, the Seabird Populations

(SEAPOP) programme was launched. Its aim is to coordinate a long-term, comprehensive, standardised, and cost-effective study of the most important aspects of seabird numbers, distribution, demography, and ecology in Norway, at Svalbard, and adjacent sea areas (Anker-Nilssen et al., 2005).

Formerly established monitoring activities — include national programmes on the mainland at Svalbard and long-term studies of seabird ecology on Røst, Hornøya, and Bjørnøya — are integrated parts of the SEAPOP programme. SEAPOP thus integrates all previous sea-bird monitoring activity into one programme (Anker-Nilssen et al., 2005a).

Activities during the two initial years were restricted to the Lofoten and Barents Sea area, but from 2008 the programme was implemented on the full national scale. The work is organised and carried out by the Norwegian Institute for Nature Research (NINA) and the Norwegian Polar Institute (NP) in close cooperation with Tromsø University Museum.

3.3.7.2 Russian zone

There is no national program to monitor seabirds in Russia. Extensive seabird studies were initiated in the Russian zone during the 1920s and1930s, and systematic studies on seabirds were started in 1938 on the Seven Islands archipelago (eastern Murman coast) at the same time as the archipelago was strictly protected as a nature reserve. It also included two of the largest seabird colonies on Novaya Zemlya: Gribovaya Bay and Bezymyannya Bay on the Southern Island during 1947–1951. Since then seabird monitoring in Russia has been based on a network of strict nature reserves (zapovedniks; IUCN category I). Only selected colonies situated within the boundaries of such specially protected areas are monitored routinely. The longest monitoring series covers the territory of Kandalaksha State Nature Reserve (KSNR; including the Seven Island reserve). Monitoring in this reserve is concentrated in three areas, including Kandalaksha Bay (White Sea), and West Murman, and East Murman at the southern coast of the Barents Sea coast. For certain species regular monitoring started in KSNR as early as the late 1920s, resulting in a nearly 80-year time series for some sites.

Monitored species include: European shag (*Phalacracorax aristotelis*); great cormorant (*Phalacracorax carbo*); common guillemot or common murre (*Uria aalge*); Brunnich's guillemots (*U. Lomvia*); black guillemot (*Cepphus grille*); Atlantic puffin (*Fratercula arctica*); black-legged kittiwake (*Rissa tridactyla*); herring (*Larus argentatus*); great black-backed (*Larus marinus*); mew gulls (*Larus canus*); arctic skua (*Stercorarius parasiticus*); arctic tern (*Sterna paradise*); and common eider (*Somateria mollissima*). Long-term monitoring data from the Murman coast was reviewed by Krasnov et al. (1995). Unfortunately, the monitoring program in remote areas of the Barents Sea coast was recently discontinued due to staff shortages and logistic problems at KSNR. Monitoring has continued in Kandalaksha Bay (total counts since 1970s), but currently with reduced coverage. In addition to population numbers, monitoring parameters include productivity, diet, and phenology.

Since 1999, several new monitoring sites have been established along the southern Barents Sea coast by the Murmansk Marine Biological Institute Russian Academy of Science (MMBI RAS). Monitoring efforts are concentrated on the Kola Peninsula both in breeding colonies and on inshore non-breeding grounds. Monitoring seabird breeding populations was established in 2000 at three sites in Western Murman (Gorodetsky Cape, since 2000) and Eastern Murman (Krutik Cape, since 2003).

3.3.8 Pollution monitoring

S. Boitsov (IMR) and J. Klungsøyr (IMR)

Monitoring chemical contamination — in both the environment and in living marine resources — in the Barents Sea was initiated by PINRO in 1986. The importance of conducting pollution monitoring on a systematic and regular basis has become more evident after exploratory drilling started in the 1990s. Different institutions take part in the regular monitoring.

Among them the:

- Institute of marine research (IMR) monitors radioactive elements, oil hydrocarbons, and various organic chlorinated and brominated compounds in fish, seawater, and sediments /;
- Norwegian Radiation Protection Authority (NRPA) monitors radioactive elements in seaweed;
- Norwegian Geological Survey (NGU) monitors inorganic substances like heavy metals in sediments (Figure 3.3.3);
- Norwegian Institute of Nutrition and Seafood Research (NIFES) monitors various organic and inorganic pollutants in seafood (fish and shrimps) (Figure 3.3.6);
- Norwegian Institute of Water Research (NIVA) monitors inorganic and organic pollutants in sediments, fish (cod), and shellfish from coastal areas and riverine inputs to the area on assignment for Norwegian Environment Agency;
- Norwegian Polar Institute (NPI) monitors various types of pollutants in marine mammals (polar bear, ringed seal) and birds (Brünnich guillemot);
- Norwegian Institute for Air Research (NILU) monitors atmospheric pollution at the Zeppelin station on Svalbard on assignment for Norwegian Environment Agency;
- MMBI monitors and determines chemical elements and compounds in sediments and the water column through its own network of stations;
- PINRO monitors heavy metals, n-alkanes, PAHs, and OC (PCB and pesticides) in sediments (Figure 3.3.4), sea water (surface and bottom water), and fish samples (cod, haddock, saithe, capelin, and long-rough dab);
- VSEGEI monitors the geological environment in Kola Bay;
- SEVMORGEO monitors the geological environment in the coastal zone of the Kola Peninsula (Figure3.3.7).

In addition to regular monitoring, the national program of geochemical, geological, and biological mapping of the seabed, the MAREANO project has, since 2006, provided detailed information on levels of certain organic and inorganic pollutants. Institutions taking part in MAREANO seabed monitoring are IMR and NGU. In 2013, NGU and SEVMORGEO jointly prepared a lithological map of the Barents Sea, which provides a basis for hydrobiological and geochemical constructions; it is currently posted on the Norwegian Geological Survey and MAREANO websites. Other Norwegian institutions also contribute to measuring contaminant levels in the Barents Sea through screening programmes, scientific projects, etc.

Further, geo-environmental work, including compilation of geochemical and geoecological maps, is part of geological mapping of scale 1:1,000,000 (MAGE and VNIIOkeangeologiya).

Types of pollutants and monitoring frequency are summarised in Table 3.3.3, and monitoring stations for fish and sediment samples for 2005-2008 are given in Figures 3.3.3 and 3.3.4.

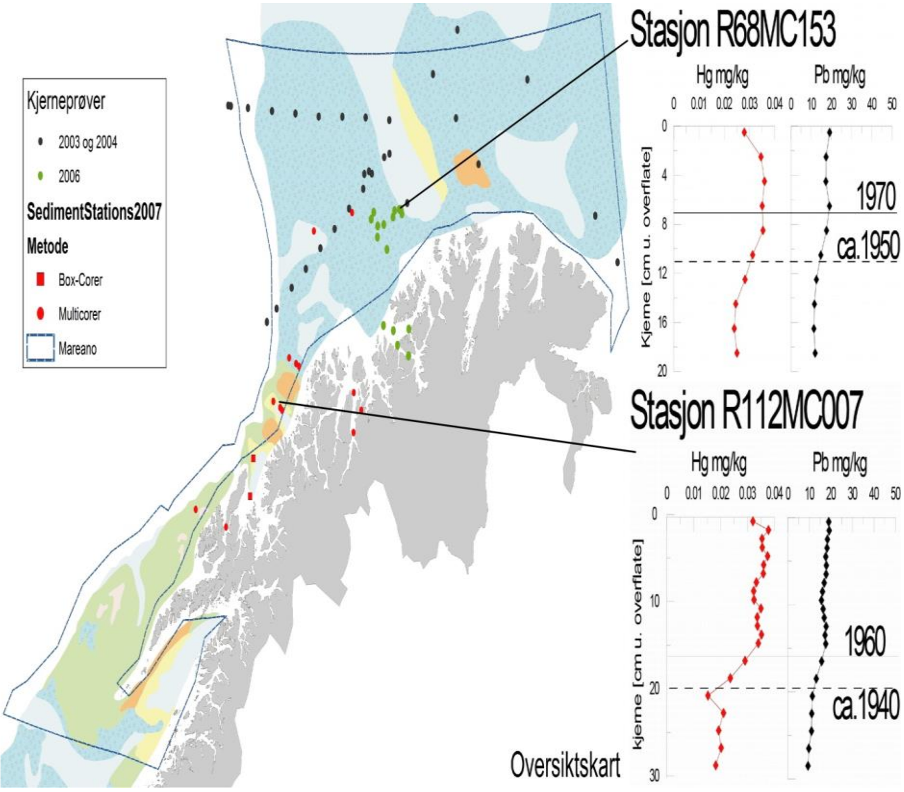

Figure 3.3.3. Norwegian Geological Survey (NGU) sediment sampling stations during the 2003-2006.

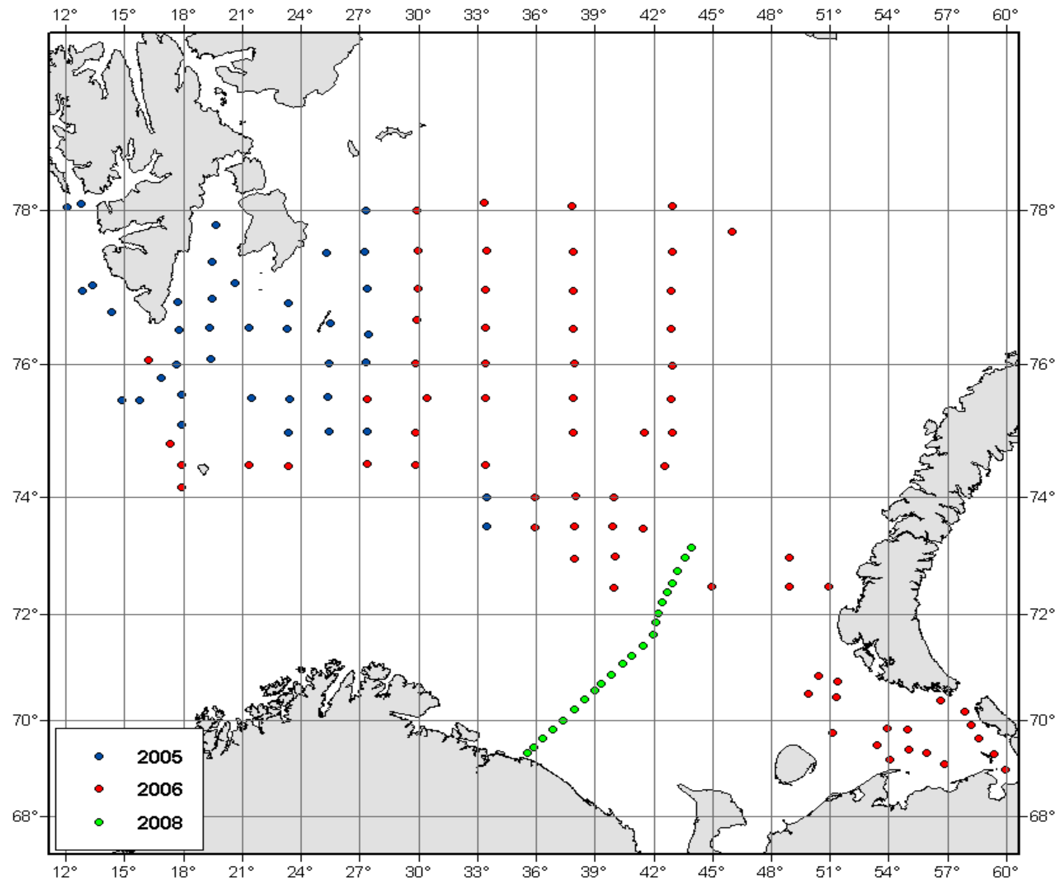

Figure 3.3.4. Sediment sampling stations of the 2005-2008 PINRO cruises

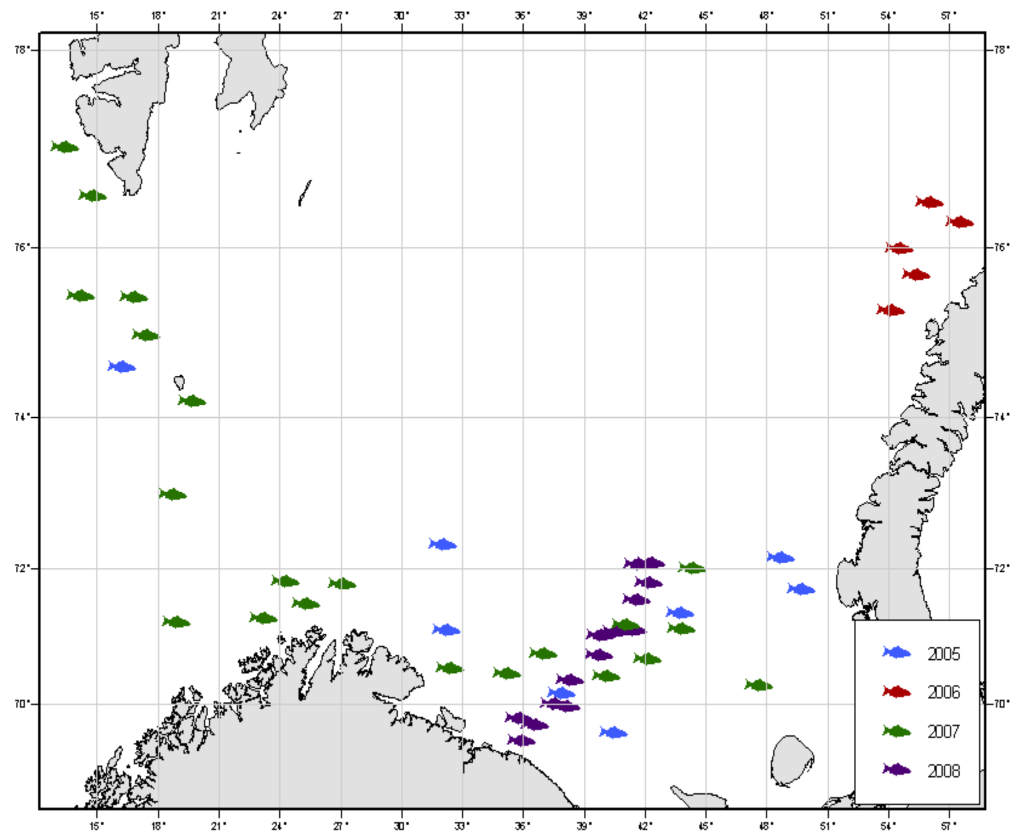

Figure 3.3.5. Fish sampling stations of the 2005-2008 PINRO cruises.

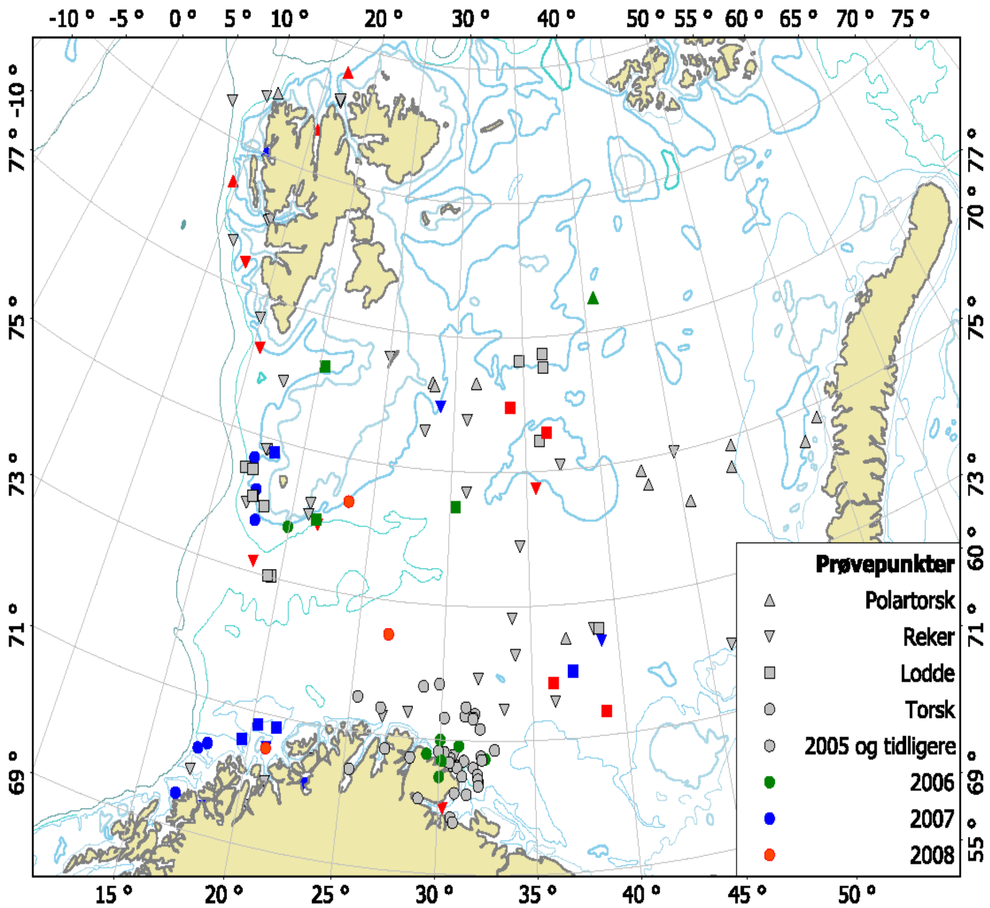

Figure 3.3.6. NIFES sampling stations for polar cod, cod, shrimp, and capelin during 2008 and earlier.

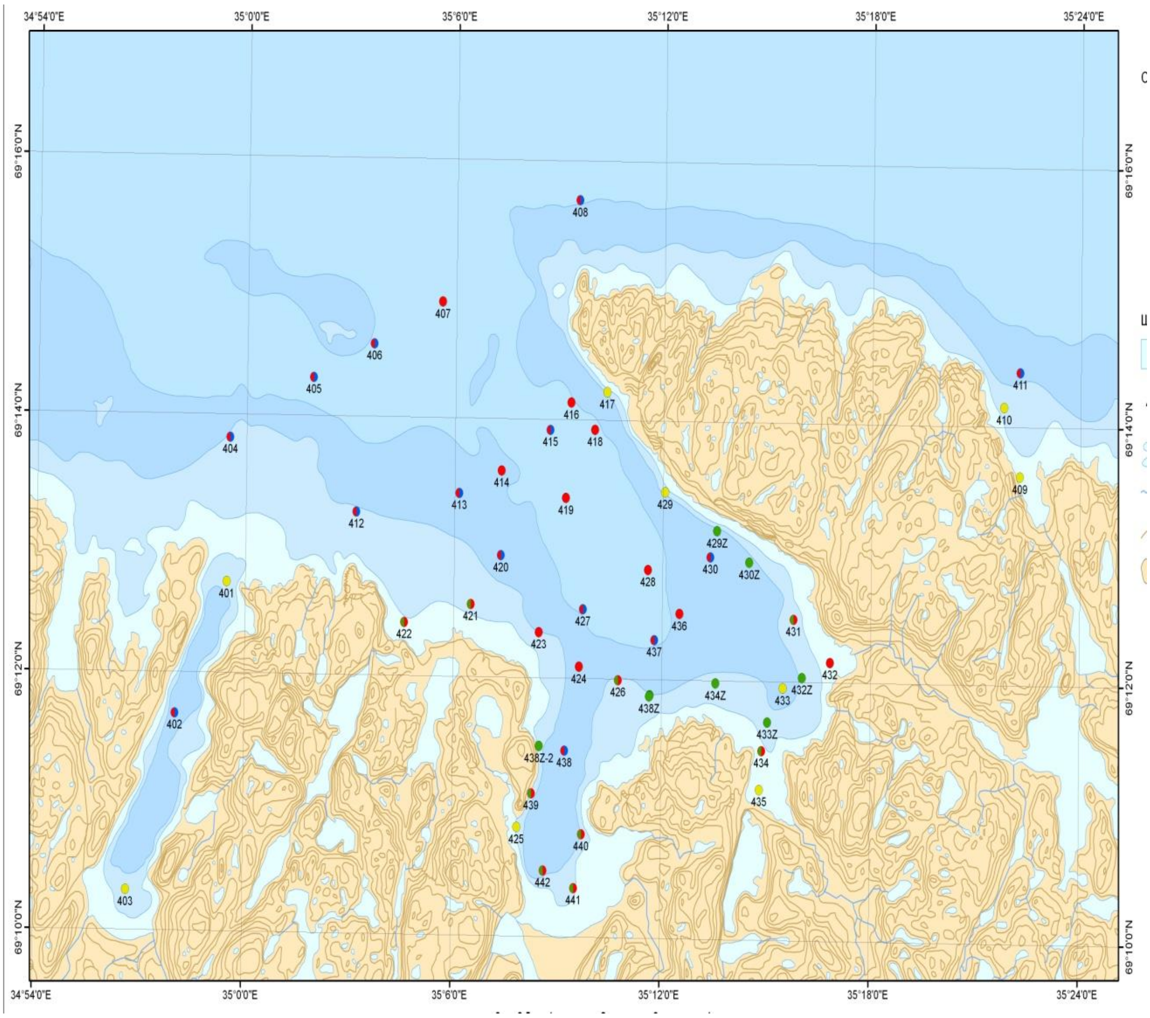

Figure 3.3.7. SEVMORGEO sampling stations in 2014 in the Teriberka Bay/Type of sampling:

Bottom sediments/ near-bottom water

Hydrophysical sond/bottom sediments

Bottom sediments

Bottom sediments/ near-bottom water/ hydrophisical sond

Hydrophysical sond

Table 3.3.3. Pollutants monitored by Norwegian and Russian institutions in the Barents Sea and periodicity of monitoring.

Pollutant type	Sediment	Water	Shellfish	Fish (muscle and/or liver)	Seaweed	Mammals and birds	Atmospheric pollution
Heavy metals	PINRO SEVMORGEO 2008-2010 and 2014 MMBI NIVA	PINRO, SEVMORGEO 2008-2010 and 2014		PINRO MMBI			/NILU annual
PAH	IMR, annual 2003- PINRO MMBI NIVA	IMR, irregular	-	IMR, every 3rd year 2002- PINRO	-	NPI	/NILU annual
THC	IMR, annual 2003-	IMR, irregular	-	IMR, irregular	-	NPI	
PCB	IMR, irregular; NIVA, annual- PINRO MMBI SEVMORGEO	-	NIFES, annual; NIVA, annual 2007-	IMR, every 3rd year 2003- , NIFES, annual 2007-; NIVA, annual 2007- PINRO	-	NPI	/NILU annual
DDT	IMR, irregular; NIVA, annual 2007-	-	NIFES, annual; NIVA, annual 2007-	IMR, every 3rd year 2003- , NIFES, annual 2007-; NIVA, annual 2007-	-	NPI	/NILU annual
Toxaphene	IMR, irregular	-	NIFES, annual	IMR, every 3rd year 2003- , NIFES, annual 2007-	-	NPI	
HCH	IMR, irregular SEVMORGEO irregular	SEVMORGEO irregular	NIFES, annual	IMR, every 3rd year 2003- , NIFES, annual 2007-	-	NPI	/NILU annual

Table 3.3. cont.

Pollutant type	Sediment	Water	Shellfish	Fish (muscle and/or liver)	Seaweed	Mammals and birds	Atmospheric pollution
HCB	IMR, irregular; NIVA, annual 2007-	-	NIFES, annual; NIVA, annual 2007-	IMR, every 3rd year 2003- , NIFES, annual 2007-; NIVA, annual 2007-	-	NPI	/NILU annual
Other chlorinated pesticides	IMR, irregular	-	NIFES, annual	IMR, every 3rd year 2003- , NIFES, annual 2007-	-	NPI	
TBT	NGU, annual 2006-	-	NIVA, annual	-	-	NPI	
Heavy metals	NGU, annual 2003-; NIVA, annual 2007-	-	NIVA, annual	NIFES, annual; NIVA, annual 2007-	-	NPI	
BFR	IMR, annual 2009- Various institutions, occasional	-	NIVA, annual; NIFES, annual	IMR, annual 2009-; NIFES, annual; SFT/NIVA, annual 2007-	-	Various institutions, occasional	/NILU annual
PFC	Various institutions, occasional	-	Various institutions, occasional	Various institutions, occasional	-	Various institutions, occasional	SFT/NILU annual
Radioactive elements	IMR, annual 1999- SEVMORGEO	IMR, annual 1999-	SSV, occasional	IMR, annual 1999-	SSV, annual 1999-; IMR, irregular	-	

3.3.9 Fisheries monitoring

Monitoring total fishery removals is an essential component of an ecosystem approach to sustainably manage the exploitation of marine systems. Effective fisheries monitoring is a valuable tool to: enforce fishery regulations and adherence to catch quotas; evaluate the effectiveness of management strategies; and provide data needed for stock assessments. In addition, effective fisheries management should include long-term catch monitoring data needed to assess the effects of fishing on the ecosystem (NMFS, 1999). Fisheries monitoring programs are also useful to evaluate whether management actions are protecting fished stocks and the communities and habitats these stocks depend upon (Bonzek, 2006).

3.3.9.1 Quota and technical monitoring

Fisheries regulations are enforced at sea, when the catch is landed, and when it is exported. At sea, the Coast Guard is responsible for inspecting fishing vessels and checking the catch against the vessel's log books. Norwegian, Russian, and other countries' fishing vessels are subject to stringent controls. Monitoring by the Coast Guard is generally considered vital to functioning of the management regime as a whole. In Norway the Directorate of Fisheries also inspects vessel activities on the fishing grounds.

Vessels over 15 meters are required to carry satellite transponders which make it possible to track their activity 24 hours a day throughout the year. When catch is landed, landings data for individual vessels are checked against their fishing rights and vessel quotas. In Norway, the Directorate also performs physical inspections of landings at landing sites. When irregularities are detected — at sea, at landing sites, or through subsequent controls — serious cases are referred to the courts.

Controlling fishing activity on fish stocks shared internationally requires close cooperation between the affected states. In 1975, Norway and Soviet Union established the Joint Norwegian–Soviet (Russian now) Fisheries Commission, and in 1976 a framework agreement was signed on mutual fisheries regulation. The Joint Norwegian–Russian Fisheries Commission, and its subcommittees, meets regularly to discuss and decide on management issues, including technical measures. There is a common understanding that protection of juveniles is an essential part of responsible management; criteria and procedures for real time area closures are jointly agreed upon. Both parties have restrictions on discarding in their legislation.

To improve exploitation patterns and reduce discards, Norway and Russia have established a suite of regulations and management measures. The primary objective is to promote an exploitation pattern that reduces fishing mortality of individual fish below a minimum legal size, and minimizes unwanted bycatch. This has been achieved through several interconnected measures, which Gullestad et al. (2015) refers to as the "Discard Ban Package".

3.3.9.2 Biological sampling/monitoring

Most current fish stock assessment models require input data on catch (biomass), fish size (length), and fish age. In the Barents Sea, detailed catch data exist for most fleets and important commercial fish stocks; in some cases, data are incomplete. Fisheries for commercial species in the Barents Sea — cod, haddock, saithe, Greenland halibut, golden redfish (*Sebastes norvegicus*), deep-sea redfish (*S. mentella*), and others — exhibit spatial differences in catch composition and catch size. Also, there are large differences in patterns of exploitation between countries.

Typically, only data from the industry (landings reports, and vessel logbooks) are used to make estimates of retained catch. However, there are examples where clear evidence of underreporting has required use of additional sources of information. Estimates of unreported catch of cod and haddock during 2002-2008 indicate that this has been a serious problem. Even if underreporting now seems to be less of a problem, continuous control and surveillance of this is necessary. Although discarding — of cod, haddock, saithe, and a number of other species, — is illegal both in Norway and Russia, it still is believed to be significant during certain periods. Data on discards are scarce, but attempts to obtain better quantitative reporting are ongoing.

PINRO conducts biological sampling of size and age composition of commercial catches through a program of onboard observers on fishing vessels. During 2013, biological samples were collected from 20 fishing vessels a total of 1034 days-at-sea in all areas fished by the Russian bottom trawl fleet. Some waters within Russian and Norwegian EEZs were not covered. In Norway, there is no onboard-observer program similar to that in Russia. The Norwegian data collection program consists of port sampling by staff from the Institute of Marine Research or individuals contracted locally, self-sampling by the Norwegian Reference Fleet (a contracted sub-sample of the entire commercial Norwegian fleet), the Coast Guard upon inspection at sea, and the Directorate of Fisheries which may deploy on-board observers/inspectors during fishing vessels.

The Joint Norwegian-Russian Fisheries Commission (JNRFC) has defined common conversion factors to convert the weights of different cod and haddock products to live (round) weights for all nations fishing for these species in Subareas I and II. These conversion factors have hitherto been fixed throughout the year, and for all sizes of cod and haddock. However, results from recent joint field studies should provide more precise conversion factors.

Analyses to estimate total catch are performed by stock-responsible assessment scientists / technicians at IMR and PINRO. However, there is no single method used to combine these various data sources — vessel log books, landings reports — to estimate total catch. This relates to the fact that landings reports are considered precise regarding catch (biomass) by species, but not as precise regarding catch location. Vessels log books are more precise regarding catch location, but less precise regarding biomass. Therefore, these data sets are combined to obtain as accurate estimates of biomass per location and season as possible.

Vessel log book data are also used when constructing catch-per-unit-effort (CPUE) series, either to tune data series in analytical assessments or as self-standing indicators of changes in stock biomass. VMS data are not used routinely to estimate total catch, but are used when a higher geographical resolution is required for logbook data or a more precise measure of effort, e.g., splitting redfish catch by species (*Sebastes norvegicus* or *S. mentella*) based on depth.

The salient question is how well do these fisheries monitoring programs characterize total fisheries removals that results in acceptably precise estimates of fish stock size and setting appropriate levels of Total Allowable Catch (TAC). Regular evaluations to answer this question should be a central component of any fisheries monitoring program. The Estimating Catch-at-Age (ECA) model — a modeling framework to estimate catch-at-age of commercially harvested fish species — can be used to estimate numbers of fish caught within each age group for shared stocks (Hirst et al., 2012 The model can be applied to Russian and Norwegian data to assess the precision of total catch and catch-at-age, and provide input data to assessment models. This will help determine the precision of assessment results used to support management advice. Plans are to apply the ECA model to both Russian and Norwegian catch sampling data to support assessment methods development.

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4 Current and expected state of the ecosystem

M.M. McBride (IMR), A. Filin (PINRO), E. Johannesen (IMR), O. Korneev (SMG), J.E. Stiansen (IMR), A.B. Storeng (Norwegian Environment Agency)

4.1 Overview of state and expected situation

Analyses of long data time series (1986-2013) indicate that during the last 8-10 years conditions in the Barents Sea have been exceptional in a number of ways. The last decade has been the warmest on record in the Barents Sea. As a result of climate change, major changes are expected in Arctic ecosystems, where warming has on average been more than twice the global average. This warming affects the entire foodweb. Therefore, it is important that data time series are collected from several trophic levels simultaneously to represent both commercial and non-commercial species, as well as the environmental parameters which determine their habitat. Our current understanding is that the average temperature in the Barents Sea rises due to increased inflow of warmer Atlantic water (Bakketeig et al., 2014).

Sea ice has been rapidly declining, and production has increased, especially in the northern Barents Sea. Phytoplankton and zooplankton species have increased both in terms of biodiversity and biomass; this is largely due to more southerly warm-water species expanding their distribution and prevalence northward, potentially at the expense of the more cold-tolerant plankton species. There also are indications that benthic communities may be changing with regard to distribution and composition of species assemblages, biomass, abundance, functional traits, and production (Jørgensen et al., 2014). In addition to cod and capelin, other communities of fish species are expanding northward in the Barents Sea. These ecological changes coincide with changes in habitats and are often directly related to changes in hydrographic patterns. How this will affect major ecosystem components and future productivity is uncertain (Bakketeig et al., 2014).

4.1.1 Overview of abiotic components

- Throughout 2013, air temperatures over the Barents Sea remained relatively high. Average air temperature was 5.0°C, and above the (1985-2013) long-term average. Average ocean temperature during 2012 was much higher than in 2011, and also higher than the long-term average. In the Kola section, average Atlantic Water temperature during 2012 was the highest observed since 1900. In 2013, water temperatures in the Barents Sea remained higher than normal, and were typical of warm and anomalously warm years, with positive anomalies increasing eastward. These higher temperatures are mostly due to the inflow of water masses with high temperatures from the Norwegian Sea, but may also be a combined effect with the reduced heat flux caused by high air temperatures. Surface waters were extremely warm due to stronger-than-usual seasonal warming; temperatures between July and October — at the 0–50 m layer in the Kola Section — were the highest observed since 1951. Deeper layers also were also warmer in 2013 than the long-term average, but colder than during 2012. The area with temperatures <0°C was larger in autumn 2013 than in autumn 2012 (ICES AFWG, 2014; ICES WGIBAR, 2014).

- Easterly winds prevailed during most of 2012, except during the periods February-April and August-September when westerly winds prevailed. During winter 2012-2013 (from the end of 2012 to March 2013) northerly, northwesterly, and northeasterly winds prevailed over the Barents Sea; during summer (from April to August) southerly, southwesterly, and southeasterly winds prevailed. In autumn (September and October) winds changed toward an easterly and northeasterly direction. In 2013, the number of days with winds more than 15 meters-per-second (m/s) was much larger than usual, and in the eastern Barents Sea it was the highest since 1981 (ICES AFWG, 2014; ICES WGIBAR, 2014).

- There has been a general decreasing trend in ice area in the Barents Sea in the last 4 decades, in particular during winter. In 2013 the winter ice area was slightly larger than the year before. During the summer 2013 there was no ice in the Barents Sea. The extent of ice coverage throughout 2013 was below the long-term average, but higher than in 2012 (ICES AFWG, 2014; ICES WGIBAR, 2014).

- During fall 2011 and winter 2012, the volume flux (inflow) into the Barents Sea was particularly low, but thereafter the inflow increased during spring 2013; information about the fall and early winter 2013 is not available.

- Salinity levels observed in Atlantic water(s) during 2012 and 2013 were close to the (1951-2010) long-term average and lower than in 2011. During the first half of 2013, values reflecting inflow of Atlantic Water at the western entrance of the Barents Sea were below average and show a trend of decrease. Negative salinity anomalies (fresher waters) were observed in coastal areas during 2013 — indicating higher than usual river runoff and/or less mixing with Atlantic Water. In Atlantic Water, average salinity observed during 2013 was slightly higher than the long-term average, and close to the 2012 value (ICES AFWG, 2014; ICES WGIBAR, 2014).

- During 2013, oxygen saturation (dissolved oxygen) levels in the southern Barents Sea were lower than in 2011, and much lower than the long-term average. (ICES AFWG, 2014). During 2014, the mean level of oxygen saturation again decreased (-1.5%) (ICES AFWG, 2014; ICES WGIBAR, 2014).

- Ocean uptake of atmospheric CO_2 accounts for nearly a third of anthropogenic carbon added to the atmosphere. This uptake is not benign, as it causes pH reductions and alterations in fundamental chemical balances that together are referred to as ocean acidification (Sabine and Feely, 2007; Sabine et al., 2004). Absorption of anthropogenic CO_2 results in lower calcium carbonate (CaCO3) saturation in surface waters, where the bulk of oceanic production occurs. This leads to a decrease in the carbonate ion concentration (Co_3^{2-}) and a reduced $CaCO_3$ saturation (Ω), which can make it more difficult for calcifying organisms to form the $CaCO_3$ shells and skeletons vital to their existence. There are large natural seasonal and inter-annual variability. Long-term monitoring is required to discern changes related to increased CO_2 emissions and their impact on ocean acidification.

4.1.2 Overview of biotic components

During 2013:

- Surface layers were well mixed during winter, with nutrients in abundance and low phytoplankton biomass. Following the bloom period in summer, phytoplankton biomass was at or near a maximum, if not grazed by zooplankton. The Barents Sea had high annual new phytoplankton production during 2008 through 2013. Essential nutrients (nitrate, phosphate, and silicate) became depleted in surface waters, and were at their annual minimum following the bloom.

- Mesozooplankton biomass (measured during August–October) was less than in 2012 and was below the long-term average. Biomass in the western/central Barents Sea was the lowest observed since the early 1990s. Mesozooplankton biomass was highest in the north-east areas of the Sea. Abundance and biomass of euphausiids (krill) varied between different areas of the Sea, but was generally higher than the long-term average. Arctoboreal *Thysanoessa inermis* was the dominant species (ICES AFWG, 2014; ICES WGIBAR, 2014).

- The shrimp stock in the Barents Sea and Spitsbergen area decreased relative to 2012, but remained above than long-term average. The shrimp stock has generally increased since the 1990's, and distribution has shifted towards the north east during the last ten years.

- Biomass of jellyfish measured during August-October was higher than in 2012 and higher than the long-term average.

- Most fishery stocks expanded their distribution northward and eastward. The cumulati*ve* biomass of pelagic fish stocks has remained consistently high since 2008. The 2013 year class of capelin appears of average size; its biomass was ≈10% higher than in 2012 and higher than the long-term average. The mature capelin stock was considerably lower than in 2012, likely due to poor feeding conditions reducing growth and maturation. Abundance of 0-group herring was above average, potentially reducing subsequent capelin recruitment. The 0-group index of polar cod was low; natural mortality has increased, possibly due to increased cod predation (ICES AFWG, 2013). The cumulative biomass of demersal fish species is the highest on record. Cod have never been recorded further north than during 2012 and 2013. The 0-group index for cod was high, and spawning stock biomass is the highest on record. Growth of immature cod is stable; however, decreases in both the maturation rate and the individual growth rate of mature cod are indicated. Haddock biomass declined in 2013 — after having reached record levels during 2009-2012 — but remains high relative to the long-term average. The 0-group index for haddock was moderate (ICES AFWG, 2014; ICES WGIBAR, 2014).

- The Barents Sea has one of the largest concentrations of seabirds in the world: 85,772 seabirds belonging to 32 different species were counted during the 2013 ecosystem survey. Density was somewhat lower than in 2012, most notably in southern areas. As in previous surveys, the highest density was found north of the polar front. These areas were dominated by Brünnich's guillemots (*Uria lomvia*), little auk (*Alle alle*), kittiwake (*Rissa tridactyla*), and Northern fulmar (*Fulmarus glacialis*). Distribution of the different species was similar to that in previous surveys. Alcids were observed throughout the study area but abundance and species distribution varied geographically. Little auks were found in the northern area, Brünnich's guillemots were found in the central and northern area, Atlantic puffins (*Fratercula arctica*) were found in the western area, and common guillemots (*Uria aalge*) were found in the south-eastern area. Among ship-followers, black-backed gulls (*Larus marinus*) and herring gull (*Larus argentatus*) were found in the south, close to the coast. Glaucous gull (*Larus hyperboreus*) was found in small numbers in the central western area, kittiwakes were found in high density in the north-east, while Northern fulmars were encountered in highest numbers in the west and south (Mauritzen and Klepikovsky, 2013b).

- It is estimated that 24 species of marine mammals occur regularly in the Barents Sea: 1,485 individual marine mammals within 12 identified species were observed during the (August – October) 2013 ecosystem survey. The highest species richness of marine mammals was in the Atlantic regions of the Barents Sea As in previous years, the most often observed species was white-beaked dolphins (≈55%). Groups of white-beaked dolphins were observed in the southern Atlantic Water and up to 81°N by Franz Josef Land; their distribution has shifted northwards, with fewer observations in Atlantic Water and more observations north of the polar front. Toothed whales were represented by killer whales, harbor porpoises, and sperm whales. Sperm whales were observed in association with Bear Island Trough, but also in the shallower south central Barents Sea. Small groups of harbor porpoises were observed in the southern and the eastern Barents Sea up to 73°N. Killer whales were observed in the north, in the south west, and south of Storfjorden in the Svalbard archipelago. Among baleen whales, minke whales, humpback whales, and fin whales were observed most frequently (≈38%). As during 2012, the number of minke whales observed was low, while the number of humpback whales observed was relatively high. These whales were predominantly observed in dense concentrations on the banks east of the Svalbard archipelago. Fewer individuals were observed in the central and the south-eastern parts of the Sea than in previous years. Six blue whales were observed along the northern shelf break and in the Hinlopen Strait. Harp seals were observed in small numbers around the Svalbard archipelago, and along the northern shelf break at 8°N. Lone walruses were observed at 80°N, north of west Spitsbergen, and between Svalbard and Franz Josef Land. Bearded seals were observed along the northern shelf break (Mauritzen and Klepikovsky, 2013a). Small catches of minke whales and harp seals are taken in the Barents Sea (ICES WGIBAR, 2014).

- Threatened and declining species

  Changes in sea ice phenology in the Barents Sea have been profound; between 1979 and 2013, the duration of the summer (i.e., reduced ice) period increased by >20 weeks (Laidre et al., 2015). Decreasing sea-ice cover is causing problems for several species of marine mammals; including ringed seals; hooded seals; harp seals; and polar bears:

➢ Ringed seals give birth to their pups in snow lairs on the fjord ice, and can only dig proper lairs if the ice is thick enough and there is sufficient snow cover. Pups on the ice surface are easy prey for polar bears, Arctic foxes and seabirds and are unlikely to survive the critical early weeks of life. Ringed seals often return to their own birthplace to give birth. Changes in ice and snow conditions may, therefore, be a serious threat to this species (NEA, 2014).

➢ Declining sea ice cover also causes problems for hooded seals during the whelping season at the end of March. Hooded seals are gregarious, and females congregate for the brief whelping season. They are dependent on large expanses of ice. The pups too face problems if the ice floes are too small, since they cannot leave the ice for the first few weeks after birth. Polar bears have been observed in the whelping areas in recent years, and predation may be another factor behind lower pup survival rates. All hooded seals in the Northeast Atlantic are considered to belong to the same stock, which whelps in the West Ice. On the basis of aerial surveys, it was estimated that there were about 82 000 individuals in 2013. This corresponds to a decline of 80–90 per cent since the 1950s, and Norway therefore gave the stock protected status in 2007. It was also classified as endangered in the 2010 Norwegian Red List. Projections of a continued decline in sea ice extent make the future of the species uncertain (NEA, 2014).

- The harp seal population is the most abundant seal species in the region. One stock whelps near Jan Mayen (the West Ice) and the other in Russia, in the White Sea (the East Ice). In 2012, it was estimated that there were about 631,000 adult harp seals in the West Ice and about 1.3 million in the East Ice. There were performed counts of the White Sea population in 2013, but the results are not yet analyzed and published. A large harvest was taken from the East Ice stock in the years after the Second World War, but strict regulation by quotas was introduced from 1965. Harp seal numbers rose rapidly after this, and catches of pups and adults were later increased again. However, numbers have declined considerably once more since 2000, and the catches have also been greatly reduced. Lower harp seal numbers are explained by a reduction in the area of drift ice and in ice thickness in the White Sea since 2000 (NEA, 2014).

- In 2004, it was estimated that there were almost 3,000 polar bears in the region around Svalbard and the Barents Sea. A new survey of the joint Russian-Norwegian population was planned to take place during August 2015. There is general agreement that ice cover will continue to decline. Polar bears are highly dependent on ice cover, since they hunt mainly from the ice. Their most important prey species, ringed seal and bearded seal, are perhaps even more strongly associated with the sea ice. The polar bear is at the top of the Arctic food chain, and will therefore rapidly be affected by changes in the populations of prey species. It has been documented that polar bears carry high loads of persistent organic pollutants (POPs), and that these pollutants affect bear health. Concentrations of new types of pollutants, such as brominated flame retardants and fluorinated compounds, are rising in polar bears, whereas there is a general decline in levels of "old" POPs such as PCBs and DDT in the Arctic. High PCB levels measured in polar bears in Svalbard are may cause effects such as:
  - Disruption of the hormonal system;
  - Damage to the immune system;
  - Reduced reproductive capacity;
  - Lower life expectancy for adults; and
  - Higher cub mortality.

  The 2015 ecosystem survey should provide a basis to assess whether the polar bear stock is increasing, stable, or declining (Norwegian Environment Agency, 2014).

- It is estimated that in total 12 whale species inhabit the Barents Sea either seasonally or year –round (Matishov, 1999). Among them five can be considered as regular inhabitants: the Arctic right whale (*Balaena mysticetus*), the Narwhal (*Monodon monoceros*), the White whale (*Delphinapterus leucas*), the Bagridae family (e.g. *Orcinus orca*) and the Little piked whale (*Balaenoptera acutorostrata*). The most abundant species of the Barents and White Seas are white whales and little piked whales, which are the traditional commercial species. The majority of Barents Sea whale species are representatives of rare or protected species included in the Red Books of the International Union for Conservation of Nature (IUCN), USSR, and the Russian Soviet Federative Socialist Republic (RSFSR) (UNEP, 2004).

- Non-indigenous species

Increased human activity and new shipping routes in the high north raises concern for the risk of introducing new species to this relatively pristine area. North of the Arctic Circle, only six non-indigenous species are reported to have established reproductive populations: two algal species (*Codium fragile* — commonly known as green sea fingers, dead man's fingers, felty fingers, forked felt-alga, stag seaweed, sponge seaweed, green sponge, green fleece, and oyster thief and *Bonnemaissonia hamifera* — commonly known as pink cotton woo); the Japanese skeleton shrimp (*caprella mutica*); two large-bodied crab species (red king crab (*Paralithodes camtschaticus*) and snow crab (*Chionoecetes opilio*); and the salmon parasite (*Gyrodactylus salaris*). The algal species were introduced to southern Norway over fifty years ago and have since spread naturally north along the coast to Troms. The Japanese skeleton shrimp, most likely spread by moving through fish farms are also observed north of Troms. Red king crabs were introduced intentionally to the Russian side of the Barents Sea in the 1960s and have since spread west to Troms. How snow crabs were introduced is still unknown; this species has had explosive growth after being first observed in the Barents Sea in 1996. The salmon parasite arrived as a "hitchhiker" on salmon smolts imported during the early days of fish farming in Norway; it is reported to have spread northward to fjords in the Skibotn region of Troms (NEA, 2014.

- Snow Crab (*Chionoecetes opilio*): Indices of the biomass of male snow crabs in the Barents Sea during 2005-2013 show continued rapid increase of the commercial stock. After first being recorded on Gåsbanken in 2004, this species has rapidly expanded its distribution, and in 2013 was found in almost the entire northern Russian economical zone (Ann Merete Hjelset, 2014). Although the number of snow crabs in the Norwegian zone is increasing, most of the population thus far is in the Russian zone. In recent years, large amounts have been observed further north and east, in shallow waters 76-77 ° N, and northwest of Novaya Zemlya; during autumn 2012 and 2013 large catches — up to several thousand individuals per haul — were taken in this area; mostly small crabs. Its prevalence in eastern parts of the Barents Sea appears linked to changing bottom temperatures. Snow crabs prefer colder temperatures; it is likely that their distribution will extend northward and eastward. If so, it is expected to also spread to areas around Svalbard. Despite the snow crab preference for low temperatures, it also occurs in coastal areas of eastern Finnmark, where exclusively large male crabs have been observed. This may indicate that male snow crabs migrate greater distances than sexually mature female crabs (Bakketeig et al., 2014).

- Red king crab (*Paralithodes camtschaticus*): Red king crabs were introduced to the Barents Sea from Kamtschatka area in Asia during the 1960s; they have since spread throughout the southern Barents Sea. This species is prevalent in areas east of Kolguyev Island, northward to Gåsbanken, and westward to Kvenangen. In the Russian zone it has spread out more into the open ocean than in the Norwegian zone. Since red king crab is a non-indigenous species, its ecosystem effects must be watched closely. Studies of its effects on benthic fauna in Varangerfjord indicate that a number of organisms inhabiting soft bottoms have been reduced or completely wiped out in areas where this crab species occurred over a long time periods; particularly echinoderms, polychaetes, and larger clams. Studies conducted in Varangerfjord also indicate that the removal of these animals which inhabit the sediments leads to reduced sediment quality resulting from reduced transport of oxygen (by these organisms) down into bottom sediments (Bakketeig et al., 2014).

4.1.3 Overview of human activities/impact

4.1.3.1 Fisheries and other harvesting

- Bottom trawl was the most widespread gear used, which had the largest effect on hard bottom habitats. Whereas, the effects of trawling on other habitats were neither clear nor consistent.
- Demersal fisheries were mixed, and had the largest effect on coastal cod and golden redfish (*Sebastes norvegicus*) due to the poor condition of these stocks.
- Pelagic fisheries were less mixed, and were weakly linked to the demersal fisheries. However, by-catches of young pelagic stages of demersal species were reported in some pelagic fisheries, and a quantity of cod was set aside from the Norwegian cod quota to cover unavoidable bycatch of cod in the capelin fishery (ICES AFWG, 2014; ICES WGIBAR, 2014).
- Work was conducted exploring the use of pelagic trawls when targeting demersal fish species to reduce the impact on bottom fauna and mixed species catches. It will be mandatory to use sorting grids to avoid catches of undersized fish.
- Fishery induced mortality (lost gillnets, encounters with active fishing gears, etc.) on fish is a potential problem but not quantified at present.
- Fisheries had minimal impact on seabird mortality (ICES AFWG, 2014; ICES WGIBAR, 2014).

4.1.3.2 Petroleum extraction (oil and gas)

The Barents Sea can become an important region for oil and gas development. Currently, offshore development is limited, both in the Russian and Norwegian economic zones, to the Snøhvit field north of Hammerfest in the Norwegian zone; this may increase in the future with development of new oil- and gas fields. In Russia commercial oil production began on 20 December 20 2013 on the "Prirazlomnoya" platform. The first batch of ARCO type Arctic oil was shipped on April 18, 2014. During September 2014, MISP "Prirazlomnaya" marked production of its 1st million of barrels of oil. The environmental risk of oil and gas development in the region has been evaluated several times, and is a key environmental question facing the region as well as an area of popular concern (Hiis Hauge et al., 2013).

4.1.3.3 Transport and shipping

Transport of oil and other petroleum products from ports and terminals in northwest-

Russia has increased over the last decade. According to Russian port administrations, customs and operators, petroleum terminals in the Russian Arctic offloaded between 9 and 12million tons of liquid hydrocarbons for export annually in the period from 2004 to 2013.Therefore, the risk of large accidents with oil tankers will increase in the years to come (ICES AFWG, 2014; ICES WGIBAR, 2014).

4.1.3.4 Aquaculture

Aquaculture is a fast growing food sector in both Norwegian and Russian waters of the Barents Sea, yet sea lice, contaminated discharge, and escaping fish remain problems. The future of aquaculture in the Barents Sea can be viewed from two perspectives: 1) the impacts of aquaculture on the marine environment; and 2) how a warming climate may impact the aquaculture industry.

Poorly managed and poorly regulated aquaculture operations can have severe negative impacts on marine environments through the release of excessive nutrients and chemicals. Escapement of farmed fish increases the risk of disease transfer. Breeding of escaped farmed fish also potentially results in genetic changes which may reduce the population fitness and productivity in wild populations (McGinnity et al., 1997; Hindar et al., 2006). The extraction of freshwater from rivers may also have a severe impact on the river habitat. Discharge of waste water can contain harmful concentrations of nutrients, chemicals and be a potential source for infection of, for example, the lethal salmon parasite *Gyrodactylus salaris*. The expansion of the aquaculture industry gives rise to two overriding concerns: the intrusion of fish farms into vulnerable marine and coastal areas, and the overall sustainability of an industry that depends on large catches of wild fish to feed farmed fish (Nagoda and Esmark, 2014) http://www.grida.no/publications/et/pt/page/2566.aspx.

Given the rapid expansion of open sea aquaculture operations in the Barents Sea, and the range of ecological impacts that either are demonstrated or suspected, there is an urgent need for better knowledge about such impacts, to implement improved monitoring programmes for the most important hazards, and also to improve procedures for risk assessments including useful environmental risk indicators and to facilitate processes which involve defining socially and politically acceptable levels of the various impacts (Taranger et al., 2014).

Higher water temperature generally has positive effects on aquaculture in terms of fish growth. The Intergovernmental Panel on Climate Change (IPCC) reported that warming and consequent lengthening of the growing season could have beneficial effects with respect to growth rates and feed conversion efficiency (IPCC, 2001).Warmer waters may also have negative effects on aquaculture since the presence of lice and diseases may be related to water temperature. In recent years high water temperatures in late summer have caused high mortality at farms rearing halibut and cod, the production of which is still at a pre-commercial stage. Salmon is also affected by high temperatures and farms may expect higher mortalities of salmon. A rise in sea temperatures may therefore favor a northward movement of production, to sites where the peak water temperatures are unlikely to be above levels at which fish become negatively affected. An increase in severe weather events can be a cause of escapes from fish pens and consequent loss of production. Escapes are also a potential problem in terms of the spread of disease. However, technological developments may compensate for this. The aquaculture industry is dependent on capture fish for salmon feed.

Another important aspect of the aquaculture industry is that it is dependent on a huge supply of captured pelagic fish species to provide feed for farmed species. Fishmeal and oils are important components of the diet of many species of farmed fish, including salmon and trout. The quantity needed is so high that the industry at a global level is sensitive to rapid fluctuations in important pelagic stocks. Reduced supply of pelagic species on the international market could lead to increased prices of fishmeal. A recent assessment by the IPCC states that unless alternative sources of protein are found, aquaculture could in the future be limited by the supply of fishmeal and oils (Vilhjálmsson et al., 2013). Climate change may cause a lack of and/or variability in the market for such products, but this is also an area where research may lead to the development of other feed sources (ACIA, 2005).

4.1.3.5 Bioprospecting

Leary (2008) concludes that research and development in relation to the biotechnology potential of Arctic genetic resources and the actual commercialization of such research is occurring on a significant and ongoing basis. For Arctic communities these new commercial opportunities may bring economic benefits, but they also bring with them new challenges for sustainable management of Arctic ecosystems and resources and possibly unforeseeable social impacts. This potential problem is made more complex by the fact that the Arctic is undergoing rapid environmental change due to the impacts of climate change. With climate change many species in frozen Arctic environments — including microorganisms of the sea ice useful to biotechnology — appear threatened with extinction during the present century (Deming, 2002).

Legislative developments have occurred in several Nordic countries concerning the regulation of access and benefit sharing in relation to naturally occurring biological materials of actual or potential value commonly referred to as wild genetic resources. Some disputes may be raised by the creation of such national regimes, especially around the disputed waters of Svalbard. Leary (2008) suggests that a more coordinated regional response may be warranted in the Arctic in the future.

4.2 Abiotic components

4.2.1 Meteorological conditions

4.2.1.1 North Atlantic Oscillation (NAO)

During 2013, the NAO index changed from negative values in January–March to slightly positive values which lasted the rest of the year. During winter (2012 –2013) northerly, northwesterly and northeasterly winds prevailed over the Barents Sea; during summer (April–August) southerly, southwesterly, and southeasterly winds prevailed. During autumn (September–October) wind direction shifted to easterly and northeasterly. During 2013, the number of days with winds more than 15 m/s was much higher than the long-term average, and in the eastern Barents Sea was the highest since 1981. Figure 4.2.1 indicates that the winter NAO went from strongly positive in 2012 to negative in 2013. Despite this, mean air temperatures during 2013 over the western and eastern Barents Sea indicated prevailing positive anomalies with the highest values (up to 5°C) in the eastern Sea during January, February, and April (Table 4.2.1).

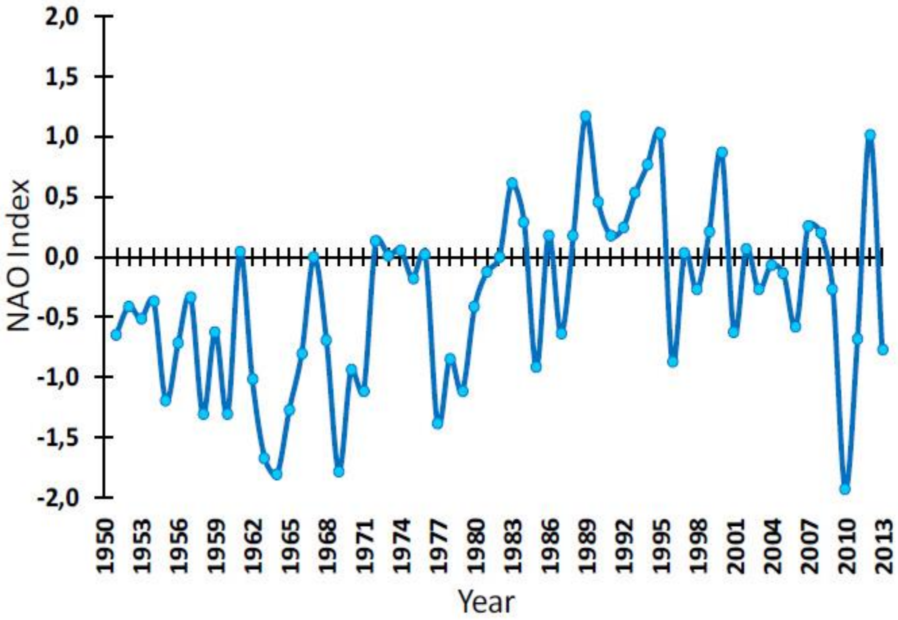


Figure 4.2.1. Winter North Atlantic Oscillation *(*NAO*)* index during 1951–2013.

4.2.1.2 Air temperatures

Air temperature data from the NOMADS (NOAA Operational Model Archive Distribution System http://nomad2.ncep.noaa.gov) website were averaged over the western (70–76°N, 15–35°E) and eastern (69–77°N, 35–55°E) Barents Sea. During 2012, positive air temperature anomalies prevailed in the Barents Sea, with the largest values (4–7°C) in the eastern part of the sea from January to April (Figure 4.2.2).

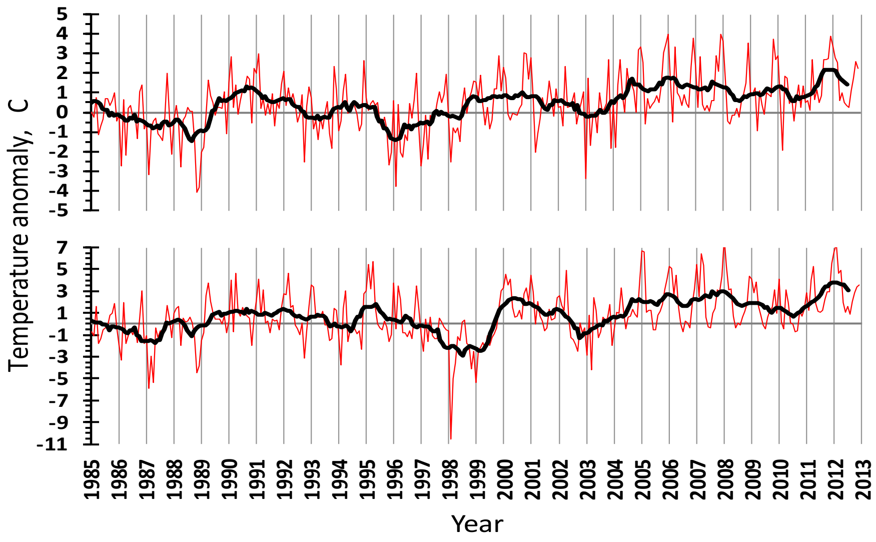


Figure 4.2.2. Air temperature anomalies over the western (upper) and eastern (lower) Barents Sea during 1985–2013 (Anon., 2013).

Table 4.2.1 summarizes air temperature anomalies at meteorological stations located in western and southern areas of the Barents Sea (Svalbard airport, Bear Island, Tromsø, Vardø, Murmansk and Kanin Nos) from late 2012 through 2013. During this period, air temperatures over the region were generally warmer than normal in early winter and summer with the largest positive anomalies (>3.0°C) occurring at Svalbard airport during January and Murmansk and Kanin Nos during May through August. During March (late winter), temperatures were generally lower than normal, with the largest negative anomaly (–5.5°C) was observed in Kanin Nos. Mean annual air temperatures for 2013 were warmer than average by 0.7–1.9°C; comparable air temperatures for 2012 were 1.1–2.4°C warmer than average. Stations in the western Barents Sea (at Tromsø, Svalbard, and Bear Island) had the smallest annual anomalies (+0.7 to +0.8°C).

Table 4.2.1. Monthly mean air temperature anomalies at weather stations located in the Barents Sea between December 2012 and December 2013, the yearly mean anomalies in 2013, maximum anomalies, and years when they were observed. Anomalies were calculated relative to the period 1981–2010.

Station	**Year/Month**													**2013 mean**	**Max/Year**
	2012	**2013**													
	Dec	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**		
Svalbard airport	2.6	3.7	1.9	–1.9	0.1	0.5	0.6	0.1	0.9	1.8	–0.6	–0.6	2.4	0.8	2.6/ 2006
Bear Island	2.0	3.0	2.1	–3.0	–0.2	1.8	2.3	1.2			–0.7	–1.0	2.0	0.8	1.9/ 2006
Tromsø	–1.5	1.0	0.2	–2.3	–0.2	3.3	2.5	–0.2	0.8	2.4	–0.2	0.1		0.7	1.4/ 2011
Vardø	–0.8	2.3	2.0	–2.7	0.6	3.1	3.1	2.4	2.9	2.9	0.4	0.4	1.9	1.6	1.6/ 2013
Murmansk	–3.8	3.6	2.2	–4.1	1.2	4.0	4.8	1.9	3.2	2.7	–0.4	1.5	2.5	1.9	1.9/ 2013
Kanin Nos	–0.9	1.9	4.2	–5.5	2.1	1.8	3.3	3.1	3.0	1.9	–0.7	1.6	2.4	1.6	1.7/ 2007

4.2.2 Oceanographic conditions

4.2.2.1 Currents and transport

Volume flux in the Barents Sea varies within periods of several years, and was significantly lower during 1997–2002 than during 2003–2006 (Figure 4.2.3). During winter 2006, volume flux was at a maximum throughout 1997-2013; whereas, during fall volume flux was anomalously low. After 2006, volume flux has been relatively low, particularly during spring and summer. During 2013, volume flux was generally larger than the 1997–2013 average**.** On annual time scales, volume flux and temperature of inflowing Atlantic Water do not vary in syncrony. Temperature showed a decreasing trend throughout 2013.

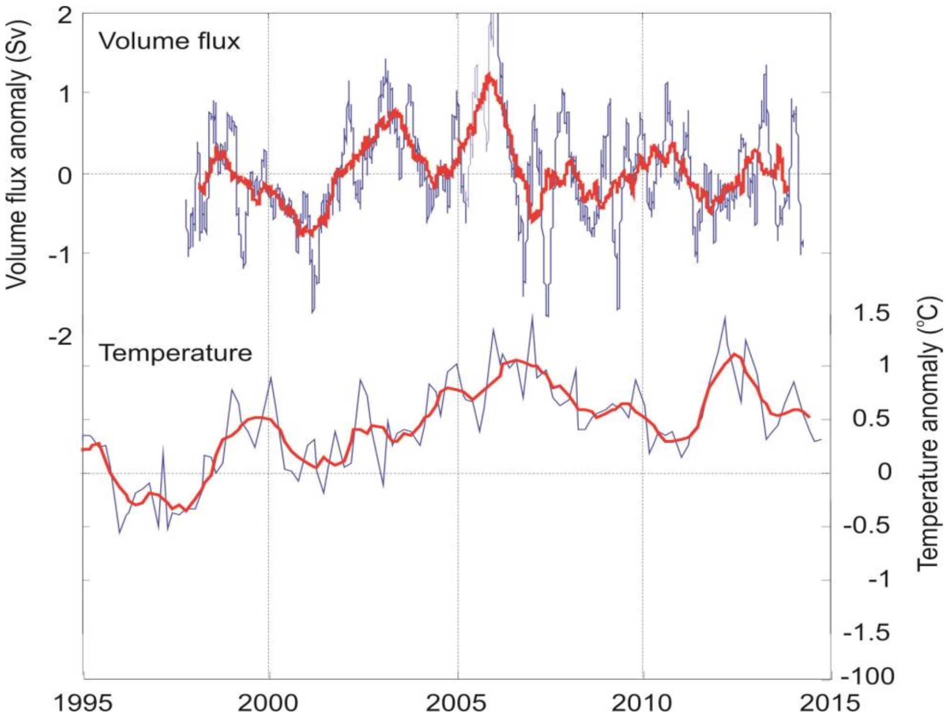


Figure 4.2.3. Observed Atlantic Water volume flux anomalies through the Fugløya–Bear Island section estimated from current meter moorings (upper) and temperature anomalies in the 50–200m layer of the water column (lower). Three-month (blue) and 12-month (red) running averages are shown.

During 2012 and 2013, monthly and annual volume-flux anomalies were calculated using a numerical model (Trofimov, 2000) for the major currents of the Barents Sea (Figure 4.2.4). In 2012, volume fluxes were 0.7–1.9σ (Sv = Sverdrup = 1 million m^3/s) higher than the long-term average, and were 0.7–1.7σ higher than those calculated in 2011. Only in the northern branch of the North Cape Current was the 2012 annual mean volume flux close to both the long-term average and the 2011 value. Throughout 2012, large positive volume-flux anomalies (ranging between 2012 and 2011 values) were observed in the Novaya Zemlya Current; during May 2012 similar anomalies were observed in all currents. In 2013, volume flux in warm currents was generally higher than the long-term average, but lower than in 2012. Mean annual volume flux in the central branch of the North Cape Current, Murman Current, and Novaya Zemlya Current was 0.5σ higher than average, while in the northern branch of the North Cape Current volume flux was lower than average, and in the North Cape and Bear Island currents volume flux was close to the long-term average. Maximum positive volume flux anomalies (1.2–1.8σ) were observed in the central branch of the North Cape Current, as well as in the Murman and Novaya Zemlya currents during June-August. Maximum negative volume flux anomalies (1.4–1.8σ) were found in the northern branch of the North Cape Current in June and July.

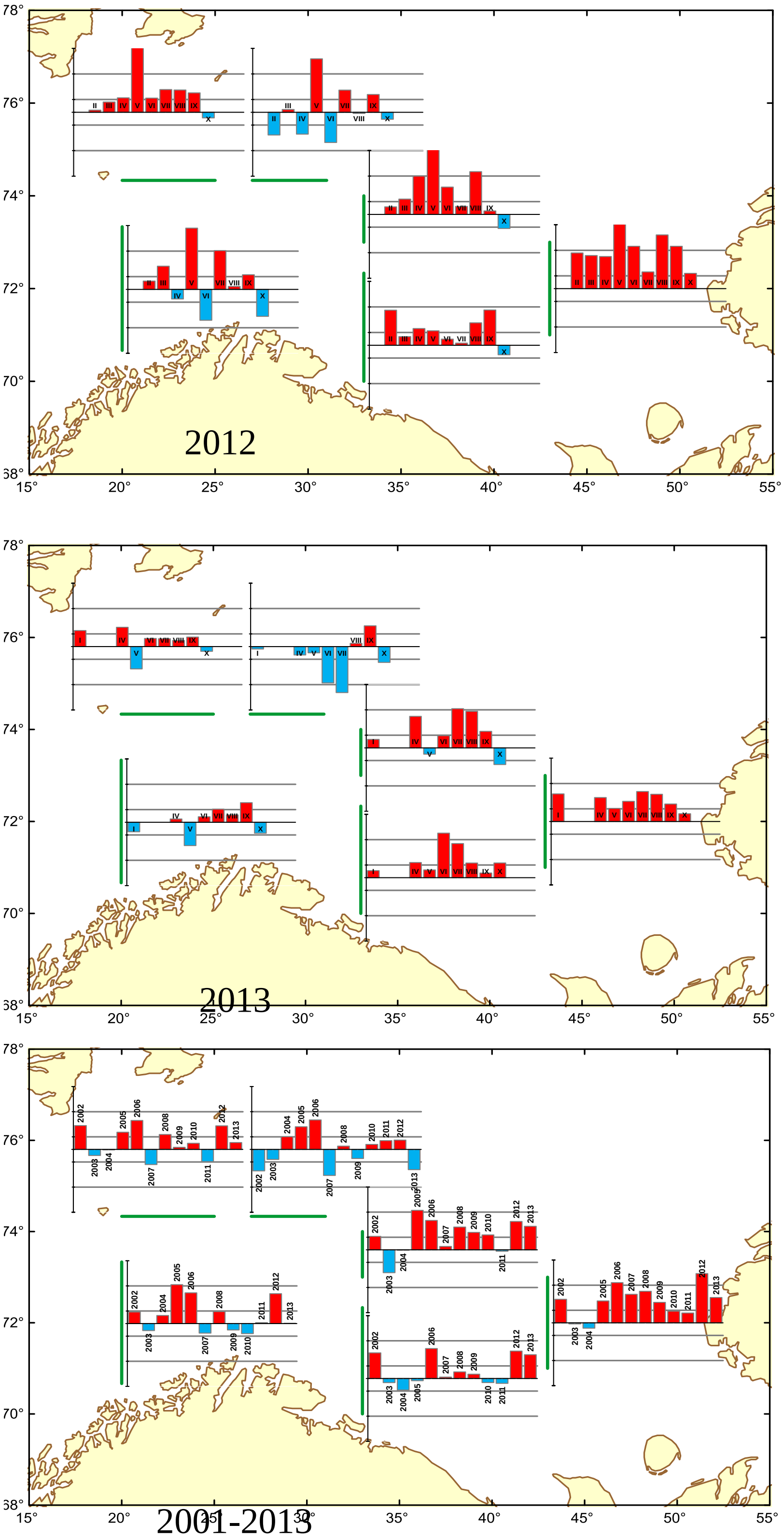


Figure 4.2.4. Calculated monthly (upper) and annual (lower) volume-flux anomalies in the Barents Sea during 2012, , 2013, and during the 2001–2013 period, Normalized by standard deviation (σ), the vertical scale range is 5σ and the vertical scale interval is 1σ, respectively.

4.2.2.2 Temperature at the surface, 100 meters, and bottom layer

Throughout 2013, positive surface water temperature anomalies prevailed in the Barents Sea. The largest anomalies (up to 4.0°C) were found in the eastern sea. Compared to 2012, the surface temperatures were much higher (by 1.3–2.7°C) in most of the Barents Sea, especially in its central and southern parts. In August–September 2013, during the joint Norwegian-Russian ecosystem survey, the surface temperatures were the highest since 1951 in about 50% of the surveyed area (ICES AFWG, 2014).

Sea surface temperature (SST) data from the IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu) were averaged over the southwestern (71–74°N, 20–40°E) and southeastern (69–73°N, 42–55°E) parts of the Barents Sea. During 2012, increasing SST anomalies took place in the Barents Sea. This increase was particularly rapid in the southeastern part, where positive anomalies increased from 0.7°C in January to 2.4°C in July (Figure 4.2.5). In the southwestern Barents Sea, positive anomalies of 0.1–1.1°C were observed throughout 2012.

Measurements of coastal waters at the Ingøy fixed station indicate that during 2013, the temperatures throughout the water column were generally higher than the 1968-1993 average, and especially during the latter half of the year (not shown).

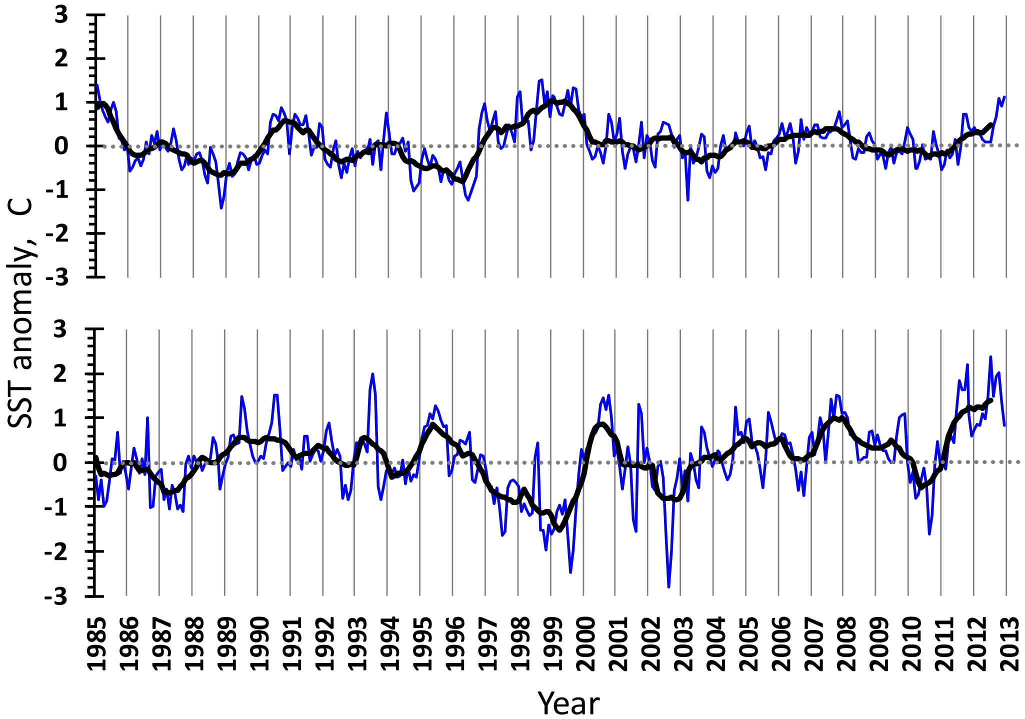


Figure 4.2.5. Sea surface temperature anomalies in the western (upper) and eastern (lower) Barents Sea in 1985–2012 (Anon., 2013).

During August–October 2013, the Joint Norwegian-Russian Ecosystem Survey of the Barents Sea was carried out. Survey measurements of surface water temperature in most areas were 1–3°C warmer than the long-term average (Figure 4.2.6). The largest positive anomalies (greater than 2.0°C) were mainly observed east of 30°E. The surface waters were generally warmer in summer 2013 as compared with summer 2012, and especially so in the southeastern areas. Northeastern areas were 0-1°C colder than in 2012.

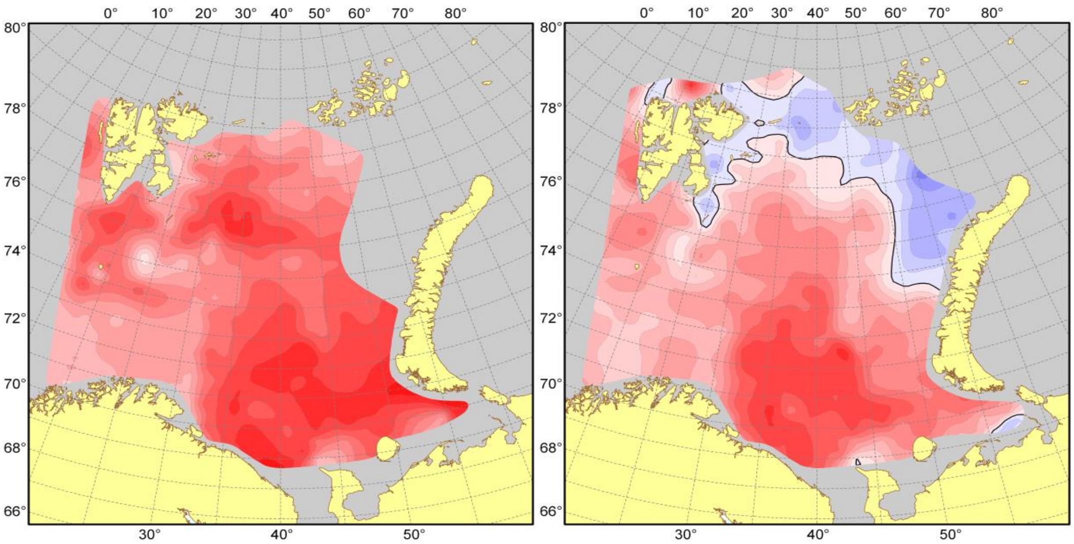


Figure 4.2.6. Surface temperature anomalies in the Barents Sea in August–October 2013 (left) and differences in temperature between 2013 and 2012 (right) (Anon., 2014).

During August–October 2013 throughout the Barents Sea, temperatures at depths below 100m were generally above the long-term average (by 0.5-1.2^{o}C); except for Spitsbergen bank, where bottom temperatures were more than 2°C warmer than normal. Bottom temperatures were generally colder than in 2012 (Figure 4.2.7). These warm temperatures were likely due to inflow of high-temperature water masses from the Norwegian Sea, and due to stronger-than-usual seasonal warming of the surface waters during summer (ICES AFWG, 2014).

The area occupied by cold water (temperatures below zero) was larger than in 2012, and cold temperatures were observed more frequently than in 2012.

Volume flux into the Barents Sea varies with periods of several years, and was significantly lower during 1997–2002 than during 2003–2006. In 2006 the volume flux was at a maximum during winter and very low during fall. After 2006 the inflow has been relatively low. During fall 2011 and winter 2012 the inflow was particularly low, but thereafter the inflow increased during spring 2013. The data time series stops in late spring 2013, thus information about the fall and early winter 2013 is not available.

In past decades, the area of Atlantic Water and mixed water has increased, whereas that of Arctic water has decreased (Figure 4.2.8). In 2013 the general temperature decrease compared to the year before lead to a slight increase in areas occupied with Arctic Water and slight decrease in areas occupied by Atlantic Water and mixed waters.

During 2013, stratification in the northern part the Barents Sea was slightly stronger than in 2012 due to slightly more ice coverage during winter. This indicates less production in these waters due to less input of nutrients from the deeper waters. In the southeastern areas, stratification during 2013 was significantly higher than in 2012, indicating less local production likely caused by the lower salinity in the coastal waters. In the southwestern areas the stratification was slightly higher in 2013 than in 2012 (Figure 4.2.9).

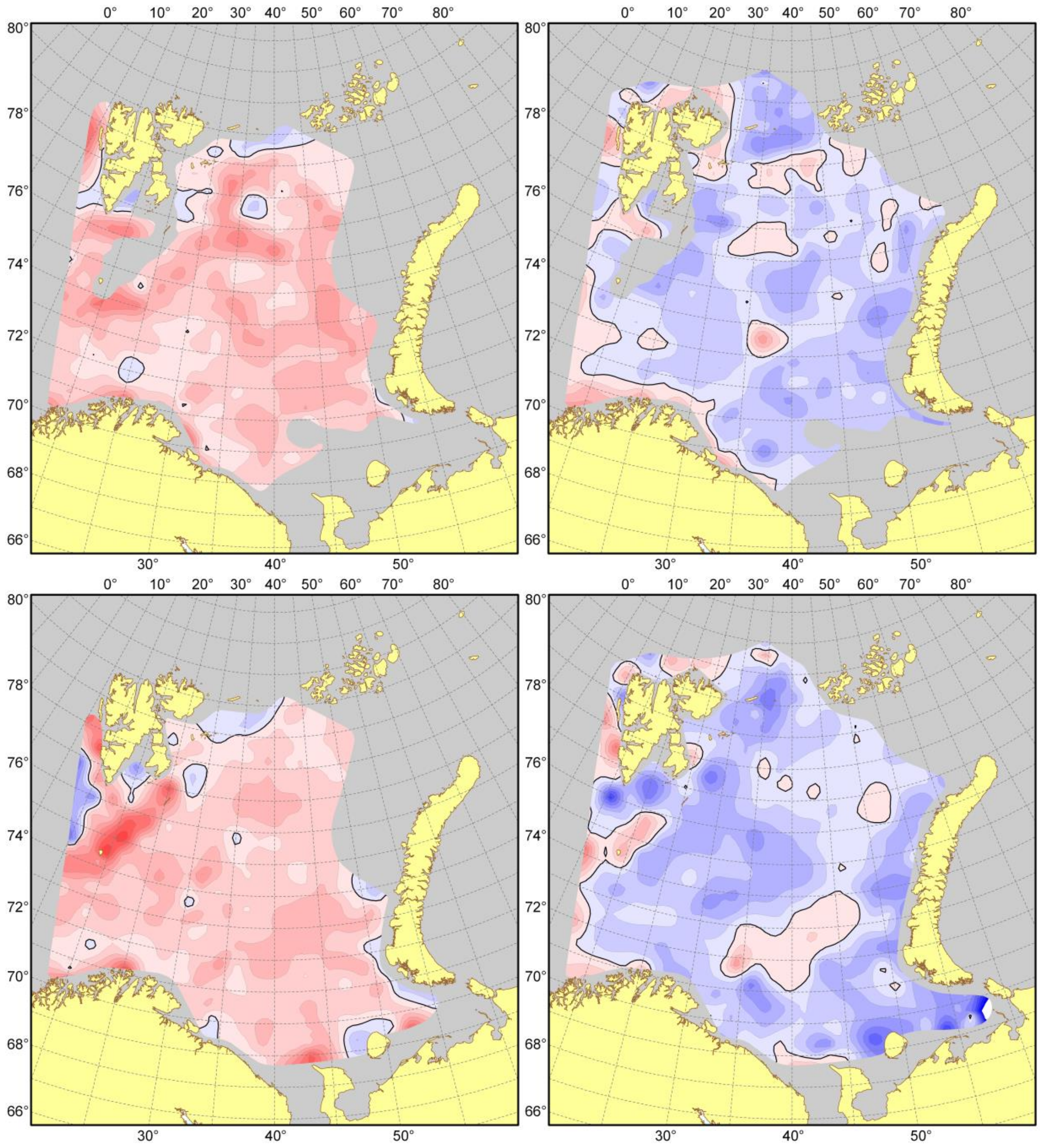


Figure 4.2.7. 100 m (upper) and near-bottom (lower) temperature anomalies in the Barents Sea in August–October 2013 (left) and differences in temperature between 2013 and 2012 (right) (Anon., 2014).

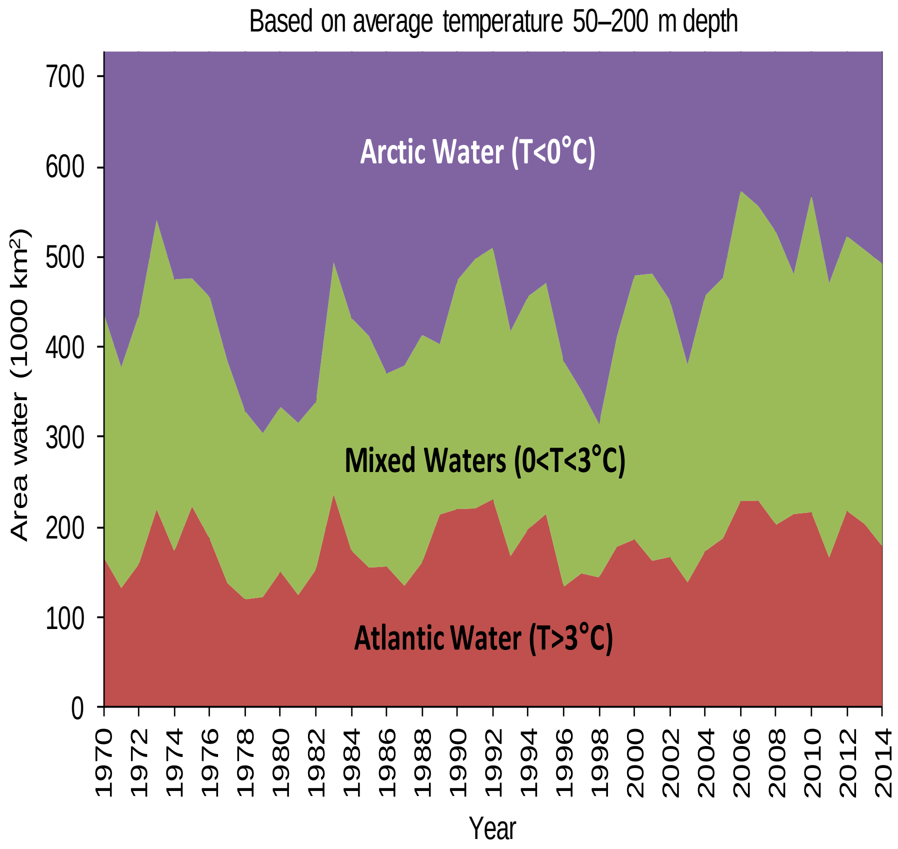


Figure 4.2.8. Area of water masses in the Barents Sea from 1970-2014 (based on average temperature 50-200 m depth).

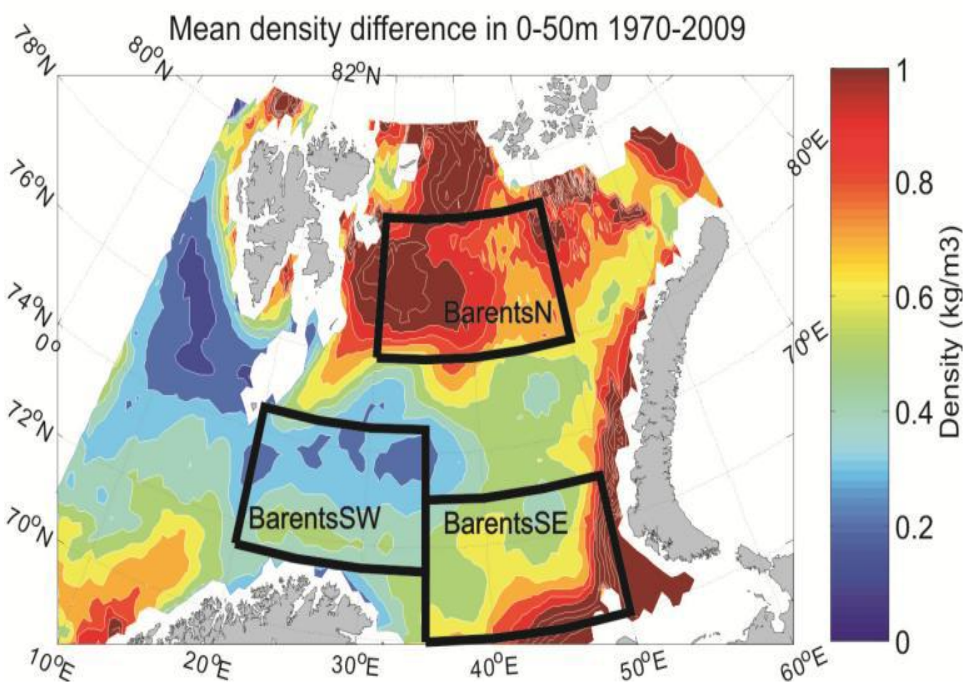


Figure 4.2.9. Mean density difference between 0 and 50 m depth during August–October. The three boxes show the geographical areas for which stratified indices have been calculated.

4.2.2.3 Temperature and salinity in the standard sections

The Fugløya–Bear Island section receives all Atlantic Water entering the Barents Sea from the southwest. Throughout 2013, Atlantic Water temperature was 0.2°C - 0.5°C above the 1977-2014 long-term average (Figure 4.2.10). Similar to temperature, water salinity also was above the 1977-2014 long-term average throughout 2013, with the anomalies ranging between 0.02 and 0.05, and trending downwards throughout the year (Figure 4.2.11).

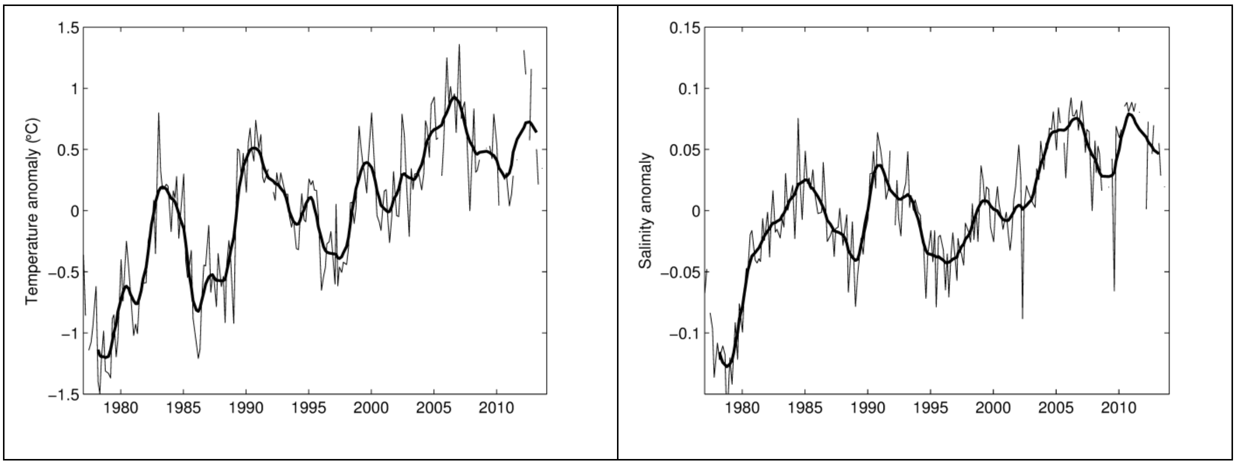


Figure 4.2.10. Temperature (left) and salinity (right) anomalies in the 50–200 m layer of the Fugløya– Bear Island section.

Throughout 2012, Atlantic Water temperatures in the Kola section also were much higher than normal, with the largest anomalies (up to 1.8°C) observed in the central branch of the North Cape Current (Figure 4.2.11); temperatures were also much higher than during 2011. In the Murman Current, positive anomalies had an increasing trend until June. In the central branch of the North Cape Current, a trend of decreasing positive anomalies started in May and was accompanied by stronger-than-usual northerly winds. Despite this fact, and typical of anomalously-warm years, positive temperature anomalies in the 0–200m layer in these currents exceeded 1.0°C almost throughout the year. Temperatures in the central branch of the North Cape Current during January–October were the highest observed since 1951, and were the highest observed in the Murman Current during January–August since 1951. It should be noted that Atlantic Water temperatures in the 150–200m layer were 1.1–1.9°C higher than normal, and throughout the year were the highest observed since 1951. In coastal waters, positive temperature anomalies (above 1.0°C) were only observed during January-February (Figure 4.2.11). During the remainder of the year, positive temperature anomalies were 0.4–0.9°C, with the smallest values observed during August and September.

During 2013, Atlantic Water temperatures at 0-200m depths in the Kola Section were 0.5–1.0°C higher than normal, but throughout the year they were 0.1–1.2°C lower than in 2012 (Figure 4.2.11). In coastal waters, positive temperature anomalies (0.6–1.2°C) were observed during 2013, with the largest values (>1.0°C) during August, November, and December (Figure 4.2.11); the highest temperatures since 19521 were observed during August and November. In the Kola Section, the 2013 annual mean temperature within the 0–200m layer was typical of anomalously warm years, but was 0.5°C lower than in 2012. In general, lower temperatures were observed in 2013 than in 2012 for both these sections (Fugløya-Bear Island and Kola).

During 2012, salinity levels in the Kola section were lower than in 2011 (Figure 4.2.11). In coastal waters, significant negative anomalies were observed during the first half of the year; they increased during the second half of the year, and reached positive values (>0.0°C) in December. In 2013, salinity levels in coastal waters and also in Murman Current of the Kola Section were generally lower than normal with the largest negative anomalies observed in July–November (Figure 4.2.11). In the central branch of the North Cape Current, salinity levels were on average 0.04°C higher than normal throughout 2013, and close to levels observed in 2012. Annual mean salinity during 2013 in the 0–200m layer in the Kola section was close to normal, and to levels observed in 2012.

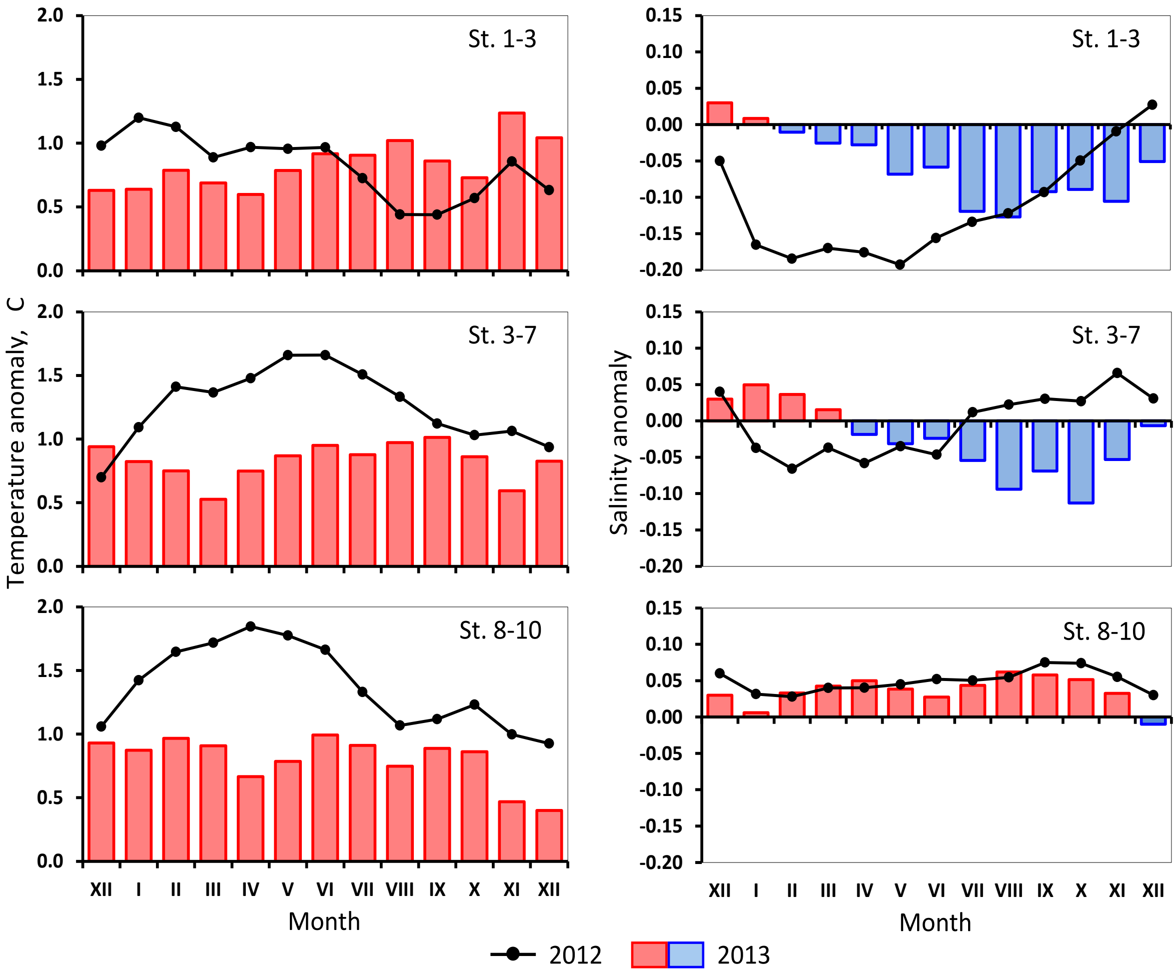


Figure 4.2.11. Monthly mean temperature (left) and salinity (right) anomalies during 2012 and 2013 in the 0–200m layer of the Kola section. St. 1–3 – Coastal waters, St. 3–7 – Murman Current, St. 8–10 – Central branch of the North Cape Current (Anon., 2013).

The North Cape – Bear Island section — sampled in April, June, and November of 2012 — had positive temperature anomalies in the 0–200m layer of the North Cape Current which decreased from 1.6°C to 0.7°C between April and November. In 2013, the North Cape – Bear

Island section was sampled in April and November. Positive temperature anomalies (0.6°C) were observed in the 0–200 m layer of the North Cape Current (Figure 4.2.12).

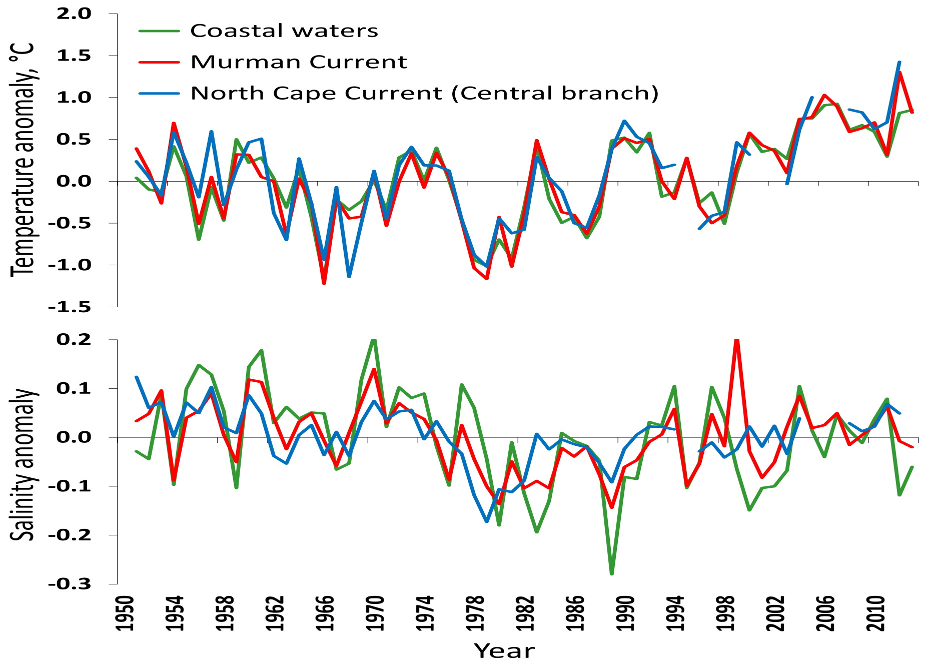


Figure 4.2.12. Annual mean temperature (upper) and salinity (lower) anomalies in the 0–200 m layer of the Kola Section in 1951–2013. Coastal waters – St. 1–3, Murman Current – St. 3–7, Central branch of the North Cape Current – St. 8–10 (Anon., 2013).

During November 2012, the Bear Island–West section (along 74°30'N) had temperature anomalies in the 0–200m layer of the eastern branch of the Norwegian Atlantic Current (74°30'N, 13°30'–15°55'E) which were 0.7°C higher than normal. In 2013, the Bear Island – West section was only sampled in November. The temperature in the 0–200m layer in the eastern branch of the Norwegian Atlantic Current was close to the long-term average with a small positive anomaly of 0.1°C.

The Bear Island–East section (along 74°30'N) was sampled three times during 2012, and had positive temperature anomalies — in the 0–200m layer of the northern branch of the North Cape Current (74°30'N, 26°50'–31°20'E) — which decreased from 1.9°C to 1.0°C between March and November. During 2013, the Bear Island – East section was sampled in April, July, and November. Positive temperature anomalies in the 0–200 m layer in the northern branch of the North Cape Current were 0.4–0.9°C with the largest values in July.

During 2012, the Kharlov section had positive temperature anomalies in the 0–200m layer of the Murman Current, which decreased from 2.0°C to 1.4°C between May and October. In 2013, the Kharlov Section was not sampled.

The Kanin section (along 43°15'E) located in the eastern Barents Sea was sampled four times in 2012. In the 0–200m layer of the Novaya Zemlya Current (71°00'–71°40'N, 43°15'E), positive temperature anomalies (1.4–2.0°C) were observed which decreased from February to

December. In August, they were as high as the historical maximum in 1954. During 2013, the Kanin section was sampled in February, August, and December. In the 0–200m layer in the Novaya Zemlya Current, positive temperature anomalies decreased from 1.5–1.6°C in February and August to 1.2°C in December.

4.2.2.4 Ice conditions

There has been a general trend of decrease for ice coverage (expressed as a percentage of the sea area) in the Barents Sea over the last 4 decades, in particular during winter. In 2013 the winter ice area was slightly larger than in 2012 (Figure 4.2.13).

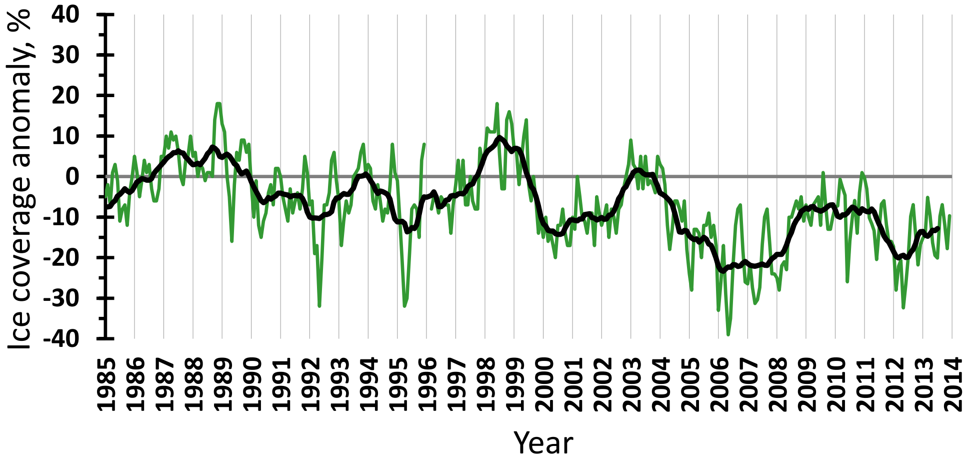


Figure 4.2.13. Anomalies of mean monthly ice extent in the Barents Sea in 1985-2013. The green line Shows monthly values, the black one – 11-month moving average values (ICES AFWG, 2014)

Meteorological conditions over the Barents Sea during winter 2011/2012, resulted in decreasing sea-ice coverage. From January through July 2012, ice coverage (expressed as a percentage of the sea area) was 17–32% below average and 7–25% less than in 2011 (Figure 4.2.13). During February and July 2012, sea-ice coverage was the smallest observed since 1951 for these months. In August and September 2012, there was no ice in the Barents Sea; the ice edge was located much farther northwards than usual, at about 83°N latitude. Also during this period, was the very rare occurrence of no ice being observed around the Spitsbergen and Franz Josef Land archipelagos. Ice formation started in the north-easternmost regions during October 2012. In the northern Barents Sea, the ice edge appeared only at the end of November. During October, November, and December, ice coverage was 14–22% less than usual, and was 1–6% less than in 2011 (Figure 4.2.13). At the end of 2012 and beginning of 2013, meteorological conditions over the Barents Sea resulted in increased sea-ice coverage. In 2013, ice coverage was still lower than normal, but higher than in 2012 (Figure 4.2.13). In January, it was only 2% higher than in the previous year. During February–June, ice coverage was 7–17% higher than in 2012, and was 5–19% lower than the long-term average. In July, ice was only observed near the Franz Josef Land archipelago. In August and September, no ice was observed in the Barents Sea. Ice formation started in the northern Barents Sea in October, when ice appeared around the Spitsbergen and Franz Josef Land archipelagos. In October, the ice coverage was 3% — an amount 12% less than usual, and 2% more than in 2012 (McBride et al., 2014).

4.2.2.5 Marine sediments

Marine sediments are mixtures of grains of varying sizes on the seabed; they serve as functionally important habitats for benthic organisms. The relative proportion of grains in different categories used to describe sediment can be classified as: mud (clay and silt) <0.063 mm; sand 0.063-2 mm; gravel 2-64 mm; cobbles 64-256 mm; and boulders >256 mm. The present day sedimentation pattern in the Barents Sea shows low or no sediment deposition on the shallow bank areas due to relatively strong bottom currents. This is in contrast to the deeper areas where bottom currents are weaker and fine sediments are deposited continuously. Within the framework of the Norwegian-Russian Environmental Commission Work Plan, an interactive map showing the grain size of marine surface sediments for the entire Barents Sea has been developed in cooperation between Russia and Norway: http://barentsportal.com/barentsportal_v2.5/index.php/en/2012-03-08-13-04-18/oceanography/marine-sediments/768-surface-sediment-distribution-in-the-barents-sea

4.2.2.6 Chemical conditions

In 2012, the oxygen saturation (dissolved oxygen) level at the bottom layer of the southern Barents Sea was much lower than the 1958-2012 long-term average, and was lower than observed in 2011. The oxygen-saturation anomaly — averaged from January to September — was –2.14% in 2012, compared to –0.79% in 2011 (Figure 4.2.14). The largest negative anomaly occurred during the first half of the year. In 2013, oxygen saturation in the Kola section increased and was slightly above the long-term average. The average level of oxygen-saturation observed from January through September 2013 was 0.35% (McBride et al., 2014).

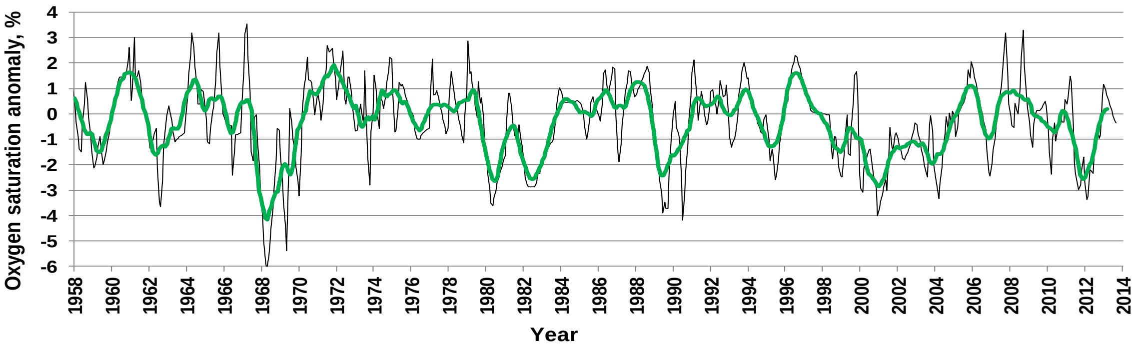


Figure 4.2.14 Monthly (black) and annual (green) oxygen-saturation anomalies at the bottom layer of the Kola section (Murman Current) over the 1958–2013 period (Anon., 2013) (Source PINRO).

4.2.2.7 Expected situation

In the Barents Sea, the long-term climate changes imply increased temperatures, less ice and a warmer ocean. Both human-induced climate change and ocean acidification may have large impacts on the Barents Sea ecosystem in the future. Accordingly, interest has increased in determining the most likely ecosystem response. Oceanic systems have a "longer memory" than atmospheric systems. Thus, a priori, it seems feasible to realistically predict oceanic temperatures much further ahead than atmospheric weather predictions. However, the prediction is complicated due to variations being governed by processes originating both externally and locally, which operate at different time scales. Thus, both slow-moving advective propagation and rapid barotropic responses resulting from large-scale changes in air pressure must be considered.

The recent warming of the Barents Sea is believed to be driven by increased ocean heat transport in combination with possible large-scale changes in the atmospheric circulation (Smedsrud et al., 2013). The Sea's marine climate is set by the ocean and the presence of warm Atlantic Water, but the atmosphere governs variability on time scales shorter than a year. If the sea ice disappears, the atmosphere may be more dominant in the future. For the future, existing downscaled models suggests a further loss of ice cover in the Barents Sea and continued warming amounting to ~4°C during summer. With the diminishing sea ice cover in the future, it is then also likely that the air-ice-ocean coupling will change. The new state of the Barents Sea may then have sea ice variability more sensitive to variations in heat flux. The atmospheric circulation is more variable than the ocean inflow, and because cold winds not only increase the heat loss but also advect more ice into the Barents Sea, the natural variability could be amplified in a future warmer climate (Smedsrud et al., 2013). The oxygen saturation of near-bottom seawater is characterized by a lack of statistically significant multidecadal trend (Titov, 2001). Despite the potential of climate change, there is no reason to expect significant changes in the oxygen saturation levels of Barents Sea waters.

4.3 Biotic components

4.3.1 Microbes

Y. Børsheim (IMR) and T. Shirokolobova (MMBI)

Expected increased temperatures related to climate change will likely affect growth rates and other biological processes. This may cause competitive conditions to change between cold-adapted bacteria and bacteria adapted to warmer waters (Børsheim and Drinkwater, 2014). Consequently, the species composition of bacterial communities may also change as temperatures change. Increased melting of sea ice is another expected change that is already an ongoing process that will, at least temporarily, decrease surface water salinity that will cause bacteria adapted to less saline condition to have an advantage. As for viruses, their populations will change whenever bacterial populations changes. Presently, we know very little about microbial species composition in the Barents Sea, so it is difficult to predict what and how such subtle changes will influence biogeochemical processes.

Perhaps more dramatic than changes in composition of the microbial community is the effect of increased fresh-water runoff expected if melting if tundra ice proceeds at the current rate or accelerates. Arctic rivers already carry large amounts of terrestrial organic material into the Arctic Ocean; this material is largely humus from bogs, but can also be a mixture of substances from the general landscape. Moreover, as temperatures increase, melting tundra may also contribute enormous amounts of organic material into the Arctic Ocean. Thingstad et al. (2007) demonstrated that increased input of organic material changes the competition for mineral nutrients (nitrogen and phosphorus) between phytoplankton and bacteria. Simply due to their small size, bacteria compete for mineral nutrients more effectively than phytoplankton. Hence, when increased organic runoff brings large amounts of organic material to the ocean, primary production decreases because bacteria use the mineral nutrients to burn off the organics (Thingstad et al., 2007). The effect is counterintuitive; large increases in organic input may decrease primary production. Therefore, increased melting of tundra may decrease total production in ocean areas receiving the organic material.

4.3.2 Phytoplankton

M.R. Kleiven (IMR), L.J. Naustvoll (IMR), S.H. Larsen (IMR), and V. Larionov (MMBI)

Among phytoplankton species in the Barents Sea, there tends to be large inter-annual and geographical variation in patterns of distribution and abundance. However, the overall annual pattern of succession is quite stable, despite variability between years for abiotic factors such as temperature. Formation of the spring bloom varies between years, and is largely determined by the degree of stabilization in upper layers of the water column.

During 2008-2013, no abnormalities have been observed in annual patterns of succession for phytoplankton species sampled along a fixed transect of Norwegian waters extending from Vardø-North (VN) and Fugløya to Bear Island (FB) (ICES AFWG, 2014). Typically, the production season has proceeded with a larger spring bloom initiating during March in coastal waters and fjord systems, then spreading out into open waters. In recent years, this bloom has been dominated by species of diatoms which commonly occur during spring, such as *Chaetoceros, Skeletonema, Thalassiosira,* and the Prymnesiophyceae *Phaeocystis*.

Up until 2012, sampling was conducted along the Vardø-North transect both before and after the spring bloom. Collected data indicate that a bloom occurred in late April/early May. Although Norwegian waters along this transect were not sampled during 2012, we can expect an increase in the occurrence of diatoms during early spring, with a subsequent decrease toward the summer. Supplementary data from nutrient samples taken along this transect indicate that an increase in primary production occurs during April/May. Again in 2013, Norwegian waters along this transect were not sampled during spring, but we assume that then also a bloom has occurred.

During summer phytoplankton are often distributed in patches consisting largely of small flagellates and dinoflagellates (*Ceratium* and *Gymnodinium*). In some years species of diatoms (mostly *Chaetoceros* spp.) can be dominant during June-August.

Coccolithophores (*Emiliania huxleyi*) occurred in blooming concentrations along the Norwegian coast during 2008-2011. Highest densities of this species were observed in western parts of the Barents Sea, in fjord systems, and close to the coast. In recent years, no large blooms or high densities of *E. huxleyi* have been observed in the open sea. During August of the last two years, another species of coccolithophore (*Coccolithus pelagicus*) has also been observed.

The overall species composition of phytoplankton observed in the Barents Sea during autumn has been stable, with larger dinoflagellates dominating followed by small flagellates and cryptophyceae. During August 2012, the diatom species (*Proboscia alata*) was abundant in western parts of the Fugløya-Bear Island transect; during August 2013, this same species was abundant along the entire transect. In recent years, the flagellate (*Dictyocha speculum*) has also been plentiful during October along the Fugløya-Bear Island Transect.

Figure 4.3.1 shows the evolution of chlorophyll *a* concentration (a proxy for phytoplankton numbers) within the upper 50 meters of the waters in the centre of the Fulgøya-Bjørnøya (FB) and Vardø Nord (VN) transects north of Norway between 71-74°N for the years 2008-2013. The period of sampling is too short, and the sampling density (in space and time) too sparse to be able to determine any trends with confidence, particularly on the VN transect which was sampled less frequently in 2012-2013. A large sinking phytoplankton bloom there is the likely cause of the high sub-surface chlorophyll observed at 45 meters in 2009. For the FB transect where the sampling frequency is greater, the depth integrated chlorophyll mean concentration has increased over the period 2008-2013. This is consistent with other studies (Drinkwater, 2011; Dalpadado et al., 2014) which have reported an increasing trend in net primary production in this region and in the Barents Sea as a whole.

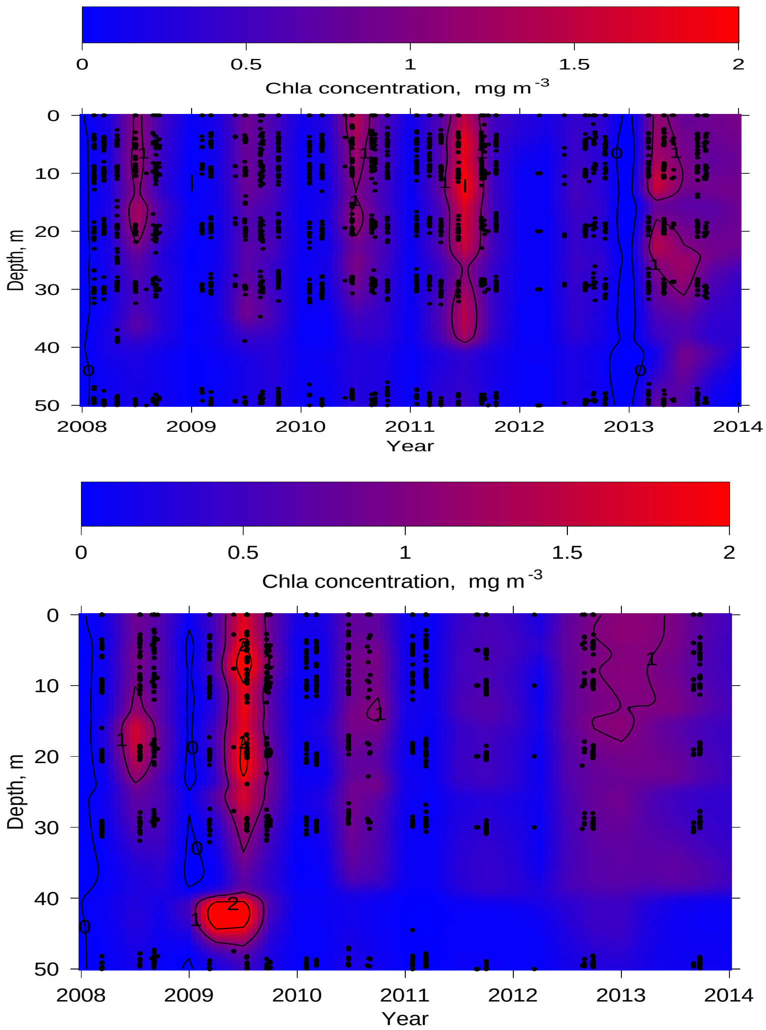


Figure 4.3.1. Seasonal cycle of Chlorophyll a concentration for the middle of the FB (top) and VN transect (bottom) within the upper 50 m. Dots indicate sample points.

In the coastal systems of the eastern Barents Sea the dominant genera are Diatoms and Dinophytes (48 and 44% respectively) in water samples taken in the summer period from 2008-2011. The sampling periods have varied between years, and this will affect the relative species abundances observed. In addition to these Chrysophytes, Chlorophytes, Cryptophytes, Prymnesiophytes, and Prasinophytes are also found in lower numbers.

In subarctic coastal ecosystems of the eastern Barents Sea, the current condition of the pelagic algal community structure can be described as stable. There are no anomalies in the community development, as evidenced by the succession stages of the micro algal community structure which match the dates registered during multi-year observations. Abundance and qualitative composition of the microalgae community are within the range of mean annual values, defined for the southern coastal areas of the eastern Barents Sea.

Seasonal fast-ice cover is the main feature of arctic coastal ecosystems and as with pelagic ecosystems of the open shelf (especially for Polar archipelagos) is almost entirely driven by seasonal dynamics of the ice cover.

In the coastal areas of arctic archipelagos, the active vegetation period of phytoplankton lasts for around 3 months, and the early- and late-spring stages, as well as the autumn one, are not present in the annual succession cycle. Occasional surveys near Franz Josef Land (FJL) are not sufficient enough at this stage to describe the annual succession cycle of pelagic microalgae. Seemingly, the spring stage of development (July-August) flows into the summer stage (August-September) followed by degradation.

According to surveys conducted by MMBI in summers 2006–2009, pelagic algaecenosis in the coastal areas near FJL is at the late-spring or summer stage of the succession cycle from late June to early October. Hence, of all microalgal flora, typically spring and summer plankton species are registered most often, namely: *Bacterosira bathyomphala*; *Chaetoceros borealis; Ch. Convolutes; Ch. Decipiens; Fragilariopsis oceanic; Thalassiosira bioculata; Th. Gravid; Th. nordenskioeldii* (probably also *Thalassiosira antarctica*); and *Dinobryon balticum*. Regularly registered autumn species include: *Protoperidinium bipes; Pr. Brevipes; Pr. Islandicum;* and *Pr. Pellucidum* which develop in open sea areas during August-September (Oleynik, 2011). However, significant interannual variations in algal composition occur near the FJL archipelago.

4.3.3 Zooplankton

A. Dolgov (PINRO), E. Eriksen (IMR), T. Knutsen (IMR), P. Dalpadado (IMR), V. Nesterova (PINRO), and I. Prokopchuk (PINRO)

This chapter focuses on the current and expected state of zooplankton communities in the Barents Sea. An overview is provided of meso-, macro-, and gelatinous zooplankton communities in the open sea and in coastal waters off the Kola Peninsula. Thoughts are also shared on how copepod communities are reacting to changing hydrographical condition in the Barents Sea.

4.3.3.1 Mesozooplankton

Horizontal distribution of mesozooplankton biomass in 2013 is shown in Figure 4.3.2. Patterns of distribution have been similar between years, even though the area of survey coverage may vary. Particularly low biomass was observed in central parts of the Barents Sea. In westernmost areas southeast of Bear Island, slightly higher zooplankton biomass was observed — somewhat similar to what was observed in 2009 and 2010. Another area with high mesozooplankton biomass was observed in the Russian sector of the Barents Sea, west of Novaya Zemlya and east of 25°E. Biomass levels were also high (>10 grams dry weight m^{-2}) in northern parts of the Russian sector (>77°N), Franz Josef Land and northward. Regional survey coverage in 2013 was more extensive than in earlier years, and indicates that biomass in this north-eastern region is very high. Mesozooplankton in this area may have good feeding conditions, and potentially less predation from pelagic fish.

During 2013, in Norwegian waters of the Barents Sea, mesozooplankton biomass was size fractionated with results between 180-1000µm and 1000-2000µm. These were among the lowest levels recorded since the peak in 2006, and the >2000µm biomass fraction was the lowest recorded since the beginning of the time series in 1988.

Based on Norwegian data, average zooplankton biomass in 2013 was estimated to be 5.16g dry weight m^{-2} in the western-central Barents Sea. This is lower than estimated for this region in 2011 (5.88), 2008 (6.48), 2007 (7.13), and 2006 (8.63). It is also lower than the average for the period 2006-2011 (6.75g dry weight/m^2), and lower than the less certain measurements taken during 2012 (not shown). In fact, such low average biomass has not been recorded since 1992. Areal coverage for the survey was above average in 2013. Although the distribution of biomass was quite similar, the low biomass region in the central-western Barents Sea seems expanded relative to previous years.

Combined Russian and Norwegian data for the entire Barents Sea produced 7.06g dry weight m^{-2} as an estimate of average zooplankton biomass in 2013. This is less than estimated in 2008 (7.15g m^{-2} dry weight), 2007 (7.7), and 2006 (8.4); but slightly higher than in 2011 (6.7). In the Russian sector alone, average biomass in 2013 was estimated to be 9.96g dry weight m^{-2}; somewhat higher than the 2011 estimate (8.05g dry weight m^{-2}).

This was above the biomass estimate for 2011-2012 (7.7-8.8 g· m^{-2}), but lower than for 2010 (11.2 g· m^{-2}). In 2012, the high biomass area in the north greatly expanded westward to include West Spitsbergen, and extended as a wide discontinuous band stretching from the central Barents Sea all the way down to its southern bounds. High biomass areas also shifted west of the Novaya Zemlya archipelago; this resulted in low biomass near the Novaya Zemlya archipelago especially in the southeast (Figure 4.3.2). Patterns of distribution for zooplankton biomass varied between 2011 and 2012. In 2011, the highest biomass (more than 10g· m^{-2}) occurred only within a small area in northeastern Franz Josef Land; different small areas of the Barents Sea had biomass estimates ranging from 7 to 10g · m^{-2} (Figure 4.3.2).

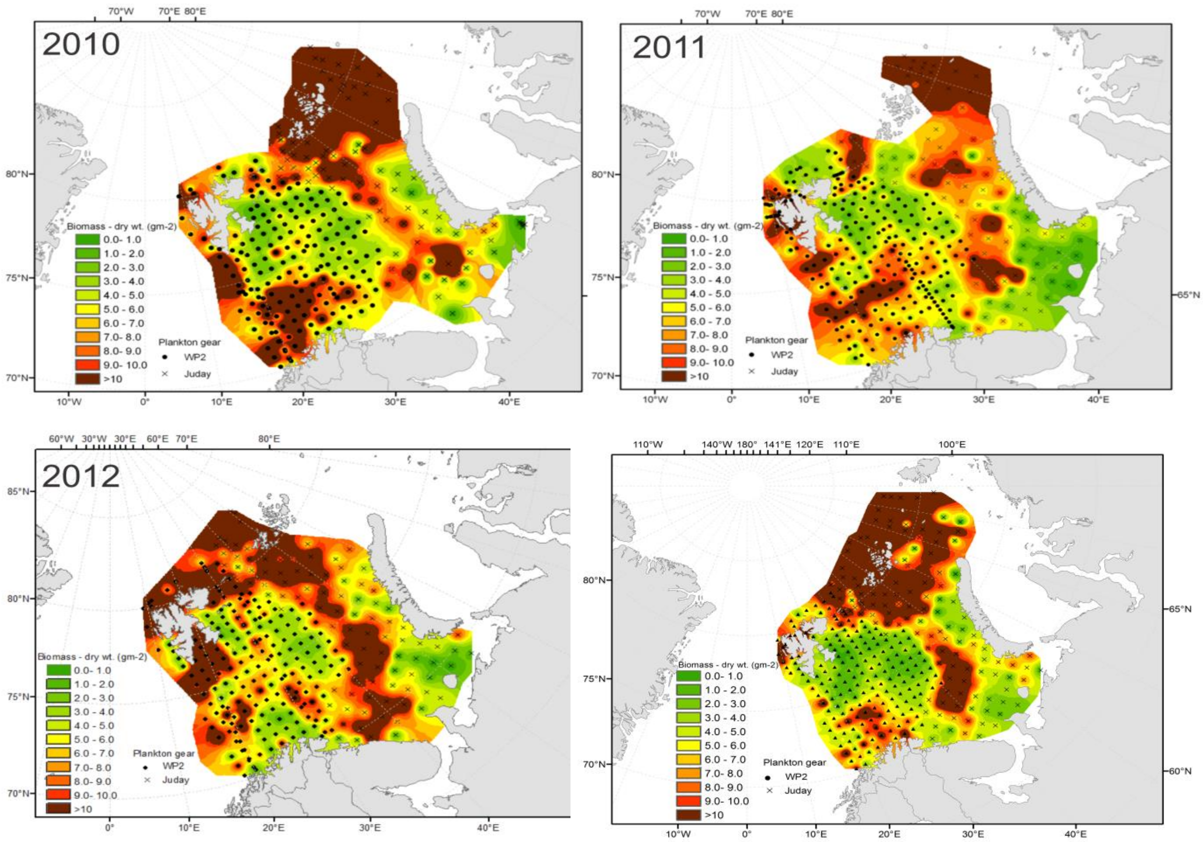


Figure 4.3.2. Distribution of zooplankton (grams dry weight m^{-2}) from the bottom (-0 m) layer during 2010 (upper left), 2011 (upper right), 2012 (lower left), and 2013 (lower right) based on Norwegian WP2 and Russian Juday net sample data (IMR/PINRO).

Even though distribution of biomass in 2013 was similar to previous years, it should be noted that the expanded area of survey coverage was an important factor that could significantly influence average biomass values. Hence, the locations of high and low biomass regions, and their annual fluctuations, are also important factors which allow better interpretation of mesozooplankton dynamics; they should be examined together with physical environmental factors and other biological ecosystem components.

The zooplankton community of the Barents Sea is typically dominated by the copepod species: *Calanus finmarchicus; Calanus glacialis; Calanus hyperboreus;* and *Pseudocalanus minutus*. However, euphausiids, chaetognaths, and in some cases pteropods also have high biomass. *C. finmarchicus* has the largest biomass in the western parts of the Barents Sea, whereas *C. glacialis* generally dominates in the northeastern parts (Orlova et al., 2009).

Northern and eastern parts of the Barents Sea

During 2011-2012, the highest zooplankton biomass levels were recorded in northern and eastern areas of the Barents Sea (Figure 4.3.2). The Arctic copepod species *C. glacialis*, *C. hyperboreus*, *Metridia longa*, and *P. minutus*, and the North Atlantic species, *C. finmarchicus*, were most abundant in this area (Figures 4.3.2 and 4.3.3).

Since 2010, the importance of the small Arctic species *P. minutus* in the zooplankton community, which traditionally is dominated by larger copepod species, has been gradually increasing. In 2012, abundance of *P. minutus* in some areas considerably surpassed the total abundance of all other copepod species (Figure 4.3.3). Also in 2011, and particularly in 2012, higher abundance of *M. longa* was recorded as far north as 80°N.

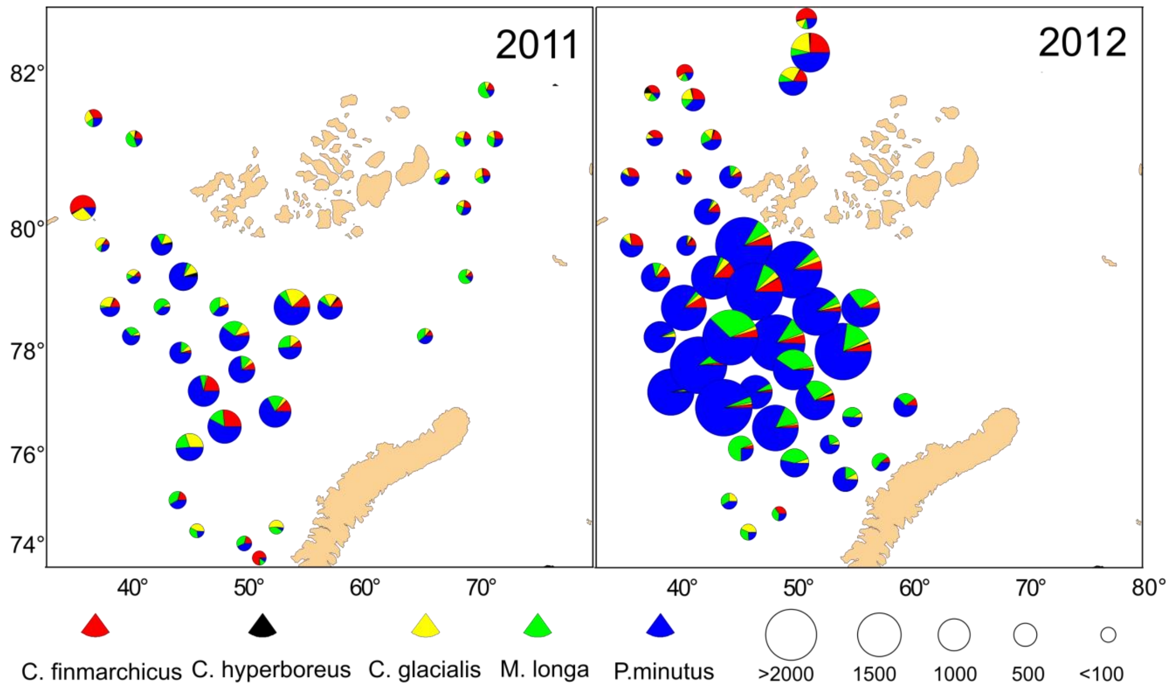


Figure 4.3.3. Relative abundance of key copepod species in the bottom-0 m layer in the Barents Sea in August-September 2011-2012 (ind. · m^{-3}).

In central and northeastern Barents Sea, estimated biomass of *P. minutus* was similar to that of *C. glacialis* and peaked at 177-212 mg·m^{-3} (Figure 4.3.4). In some areas euphausiids, chaetognaths, and hydromedusae also had high biomass estimates. *Calanus finmarchicus* was a dominant species in the western region, while *C. finmarchicus*, *P. minutus*, *M. longa*, and *C. glacialis* were dominant copepod species in the northeastern Barents Sea.

Abundance, distribution, and biomass of mesozooplankton all vary considerably from year to year in different parts of the Barents Sea. Variation in temperature, advection from the Norwegian Sea, local growth conditions, and predation pressure, along with timing of recruitment with respect to the regional coverage, are all factors that to a greater or lesser degree may contribute to such variability (Orlova et al., 2009).

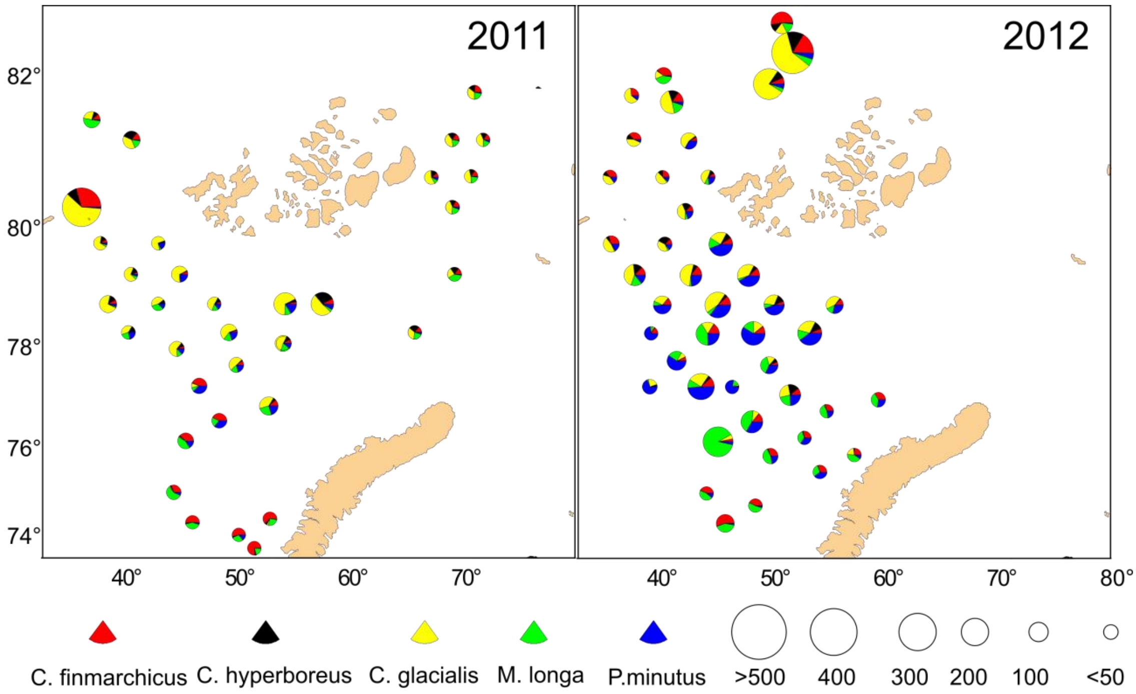


Figure 4.3.4. Estimated biomass of key copepod species in bottom-0m in the Barents Sea during August-September 2011-2012 (mg · m^{-3}).

The Kola section

In the Kola section, located in the southern part of the Barents Sea north of the Kola Peninsula, *C. finmarchicus* is a dominant species in terms of both abundance and biomass. Its abundance varied considerably during 2008-2012 (Figure 4.3.5). The population consisted of all developmental stages, but naupliar and copepodite (CI-CIII) stage individuals dominated in terms of abundance. During 2008-2009, abundance of *C. finmarchicus* was lowest for the period studied, and did not exceed 740 ind. · m^{-3} on average; they also declined in abundance between surface to bottom layers. Highest abundance of *C. finmarchicus* was observed in 2010 (up to 31,000 ind. · m^{-3} at one station), and its maximum abundance(8,700 ind. · m^{-3} on average) was observed at 50-100m depths. Its abundance level declined approximately by a factor of two between the 100m and bottom layer (4,570 ind. · m^{-3}). During 2011 and 2012, levels of abundance for *C. finmarchicus* were almost the same (approximately 1,300 ind. · m^{-3}). In 2011, its vertical distribution was quite similar to that observed in 2010. During the period of investigated, nauplii and copepodites CI-CIII dominated in both 0-50m and 50-100m layers. In both 2010 and 2011, they were also abundant in the 100m to bottom layer. Abundance of late copepodite (CIV-VI) stage individuals was low, but their relative percentage was higher at depths above 100m (Figure 4.3.5). In 2012, the portion of copepodite CIV stage individuals was high at 0-50m depth in the southern half of transect. Their percentages gradually increased with increasing depth, and they were the most abundant group in the deepest layer. Results of the International Ecosystem Survey of Pelagic Fishes in the Nordic seas, conducted May-June 2012, indicated that water temperature in the Kola section corresponded to levels typical of warm and anomalously-warm years. Consequently, the development rate of *C. finmarchicus* was accelerated, and a high portion of individuals reached copepodite stage CIV, making it the dominant group forming the bulk of plankton biomass.

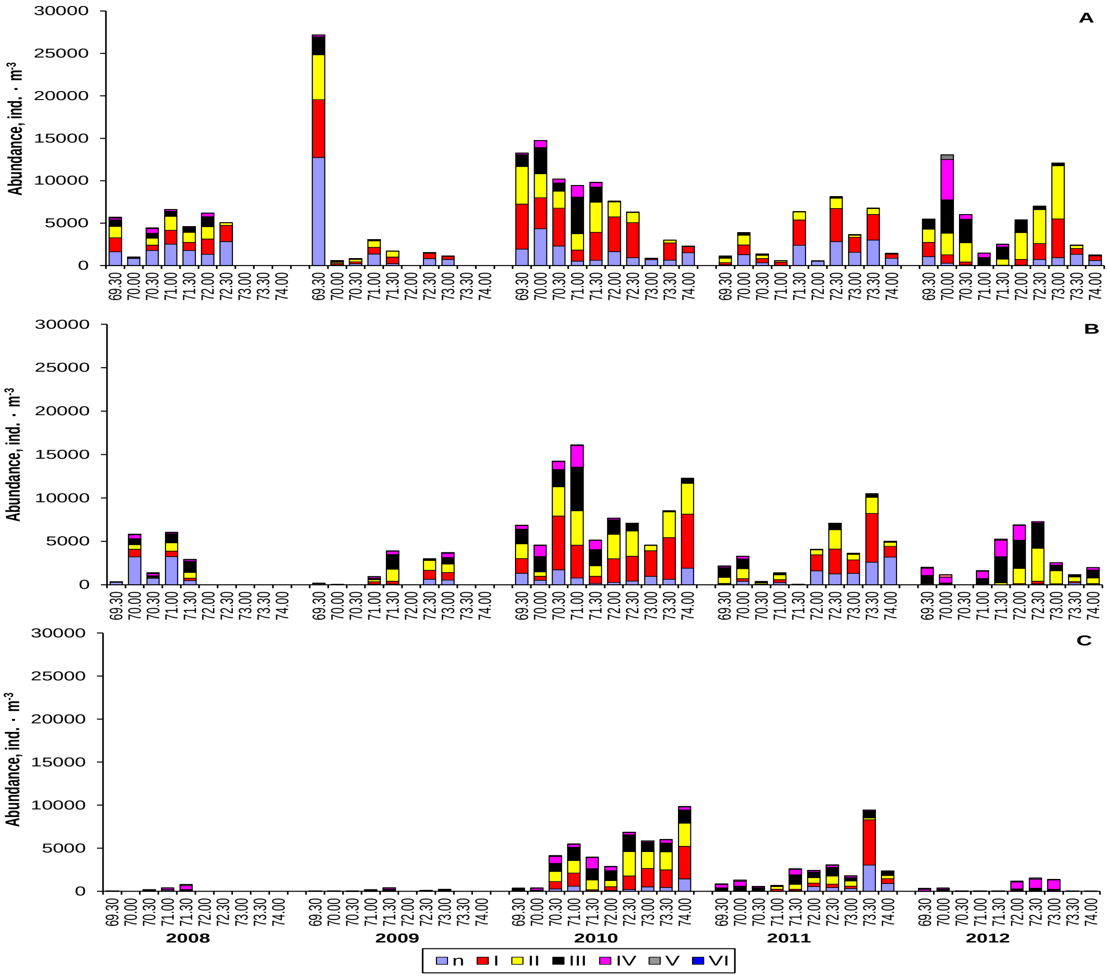


Figure 4.3.5. Abundance of *C. finmarchicus* (ind. · m^{-3}) in Juday net catches at 0-50m (A), 50-100m (B), and 100m-bottom (C) layers in the Kola section during late May-early June, 2008-2012.

The Fugløya-Bear Island (FB) transect

The Fugløya-Bear Island (FB) transect has fixed positions located at the western entrance to the Barents Sea. Normally, 5 to 8 stations are sampled depending on weather conditions. Data collected between 2004 and 2012 from four locations, representing different water masses — coastal, Atlantic, and mixed Atlantic/Arctic — were analyzed. Abundance estimates of three species (*C. finmarchicus*, *C. glacialis*, and *C. hyperboreus*) are shown in Figure 4.3.6.; *C. finmarchicus* displays large inter-annual variations in abundance. The highest levels of abundances were recorded during 2010 along almost the entire transect; at the northernmost position (74º00’N), however, abundance was considerably lower. The data time series indicates that abundance of *C. finmarchicus* has been highest at the 73º30’N position. As would be expected, *C. glacialis* had highest abundance at the two northern-most positions where Atlantic and Arctic waters mix. This species is subject to large inter-annual variations.

In recent years, its abundance has been considerably below the long-term average for the two northernmost positions.

Variability in the abundance of dominant *Calanus* species along the Fugløya-Bjørnøya transect (cf. Figure 4.3.6) suggests that abundance of the Arctic species (*C. glacialis and C. hyperboreus*) has decreased since 2004; while abundance of *C. finmarchicus* has increased, particularly at northern-most positions along this transect.

Calanus helgolandicus, a more southerly species with a different spawning period during autumn, has regularly been observed in the Fugløya-Bjørnøya section, particularly during the period from December to February (Dalpadado et al., 2012). This species is similar in appearance to *C. finmarchicus*; in recent years, it has been observed more frequently in the North Sea and southern parts of the Norwegian Sea (Svinøy transect). A report published in 2012, used the 1995-2011 data series to show intermittent high proportions of this species during winter within the Fugløya-Børnøya transect. During this same winter period, however, *C. finmarchicus* is normally inactive as it overwinters in deeper waters. There is no evidence of an increase in the relative proportion *C. helgolandicus* during this time period, which suggests that this species has not increased in absolute abundance at the entrance to the Barents Sea.

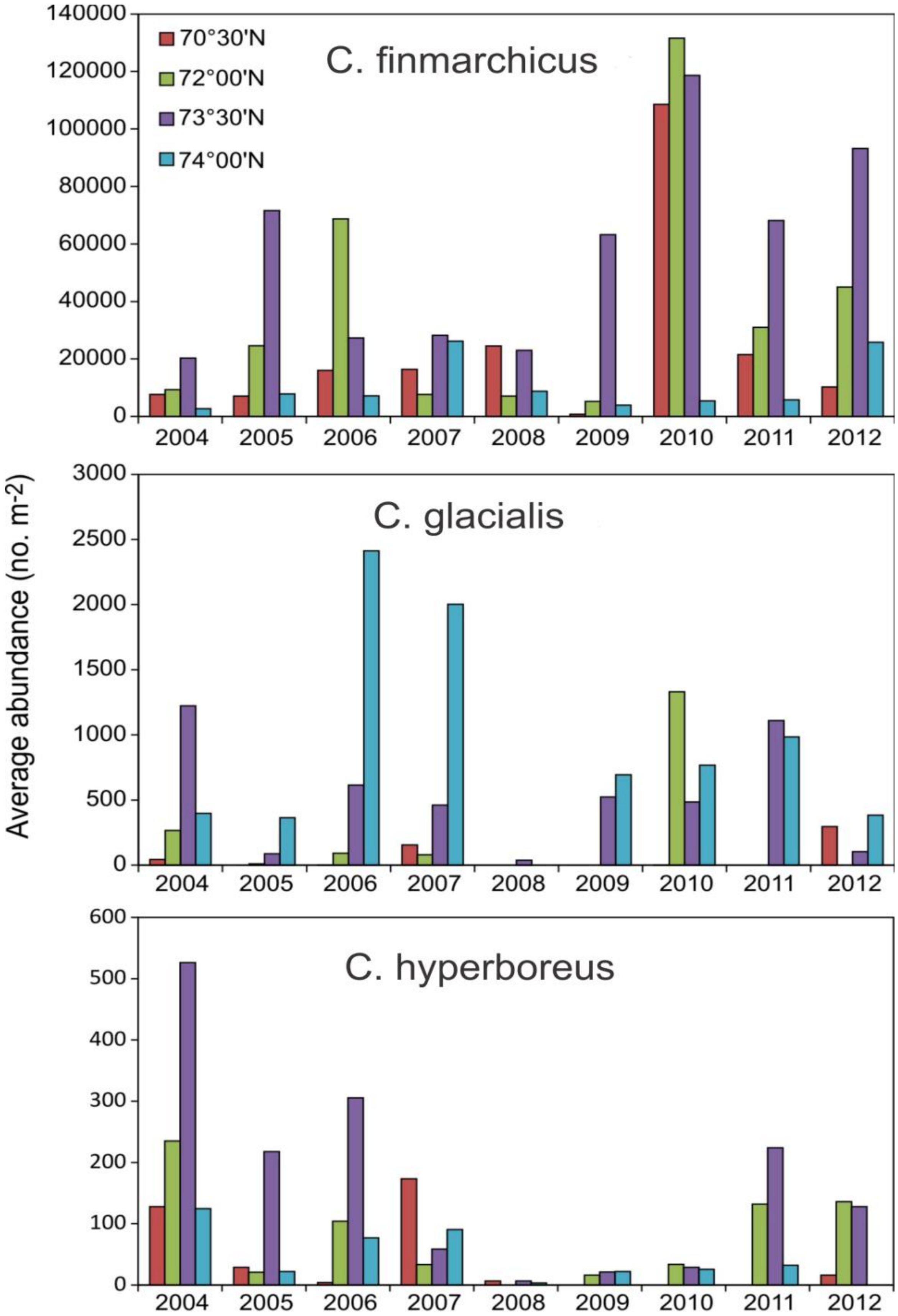


Figure 4.3.6. Calanus abundance along the transect Fugløya-Bear Island during the period 2004 - 2012. On a few occasions, when stations were lacking at a particular position, stations closest to that position were analyzed.

4.3.3.2 Macrozooplankton

Samples were collected by PINRO in the Barents Sea during the 2011-2012 autumn bottom-trawl survey to estimate pre-winter euphausiid assemblages. During 2012, further decrease in the abundance of euphausiids was recorded in some areas; at the same time their abundance increased in other areas. However, euphausiid abundance generally remained above the long-term mean in all areas of the Barents Sea (Figure 4.3.7).

Decreased total biomass in some local areas is indicative of the sharp decline in abundance in the eastern Barents Sea (Figure 4.3.8). The most prominent development in 2012, however, was a sharp increase in abundance of two boreal spceies, i.e., *Thysanoessa inermis* (by a factor of 7 in the northwest and by a factor of 3 in the east) and *Meganyctiphanes norvegica* (by a factor of 4 in the northwest and coastal areas, and by a factor of 2.5 - 3 in the central and eastern Barents Sea) (Figure 4.3.9). Slightly increased abundance of the *T. raschii* was observed in all exept eastern areas. Whereas, abundance of *T. longicaudana* decreased almost throughout the area of investigation.

During 2012, substantial recruitment of 0+ age group individuals was observed for: *T. inermis* (in all the areas); *M. norvegica* and *T. longicaudana* (in northwestern and western areas); *T. raschii* (in eastern areas). Substantial recruitment of 1+ age group *T. inermis*, *T. Raschii*, and *M. norvegica* was observed in all areas.

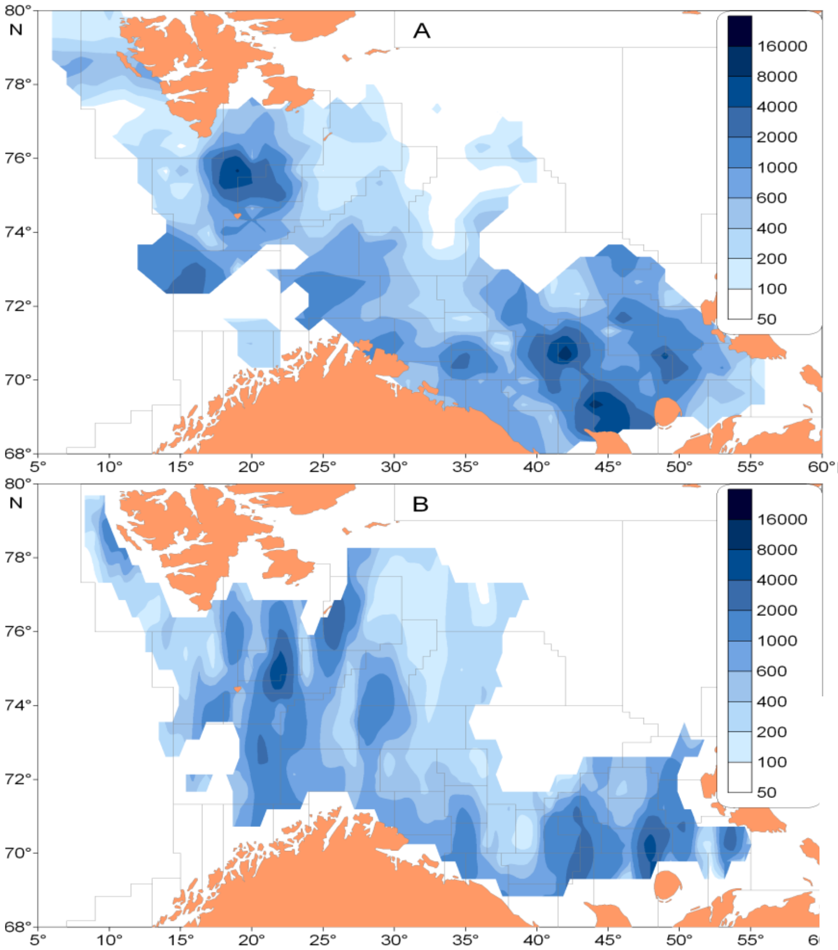


Figure 4.3.7. Distribution and abundance (ind. · 1000 m^{-3}) of euphausiids in the near-bottom layer during autumn 2011 (A) and 2012 (B).

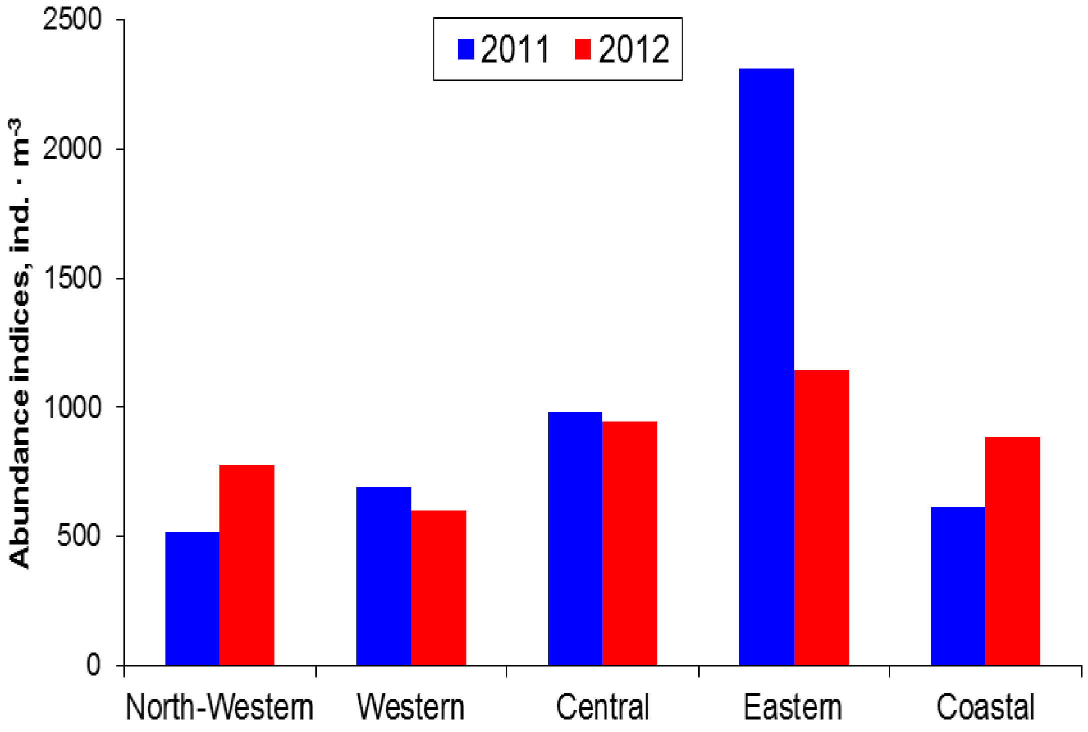


Figure 4.3.8. Mean abundance indices (ind. · 1000 m^{-3}) of euphausiids in North-Western, Western, Central, Eastern, and Coastal areas of the Barents Sea during autumn 2011 and 2012 (based on Russian trawl-net sampling data).

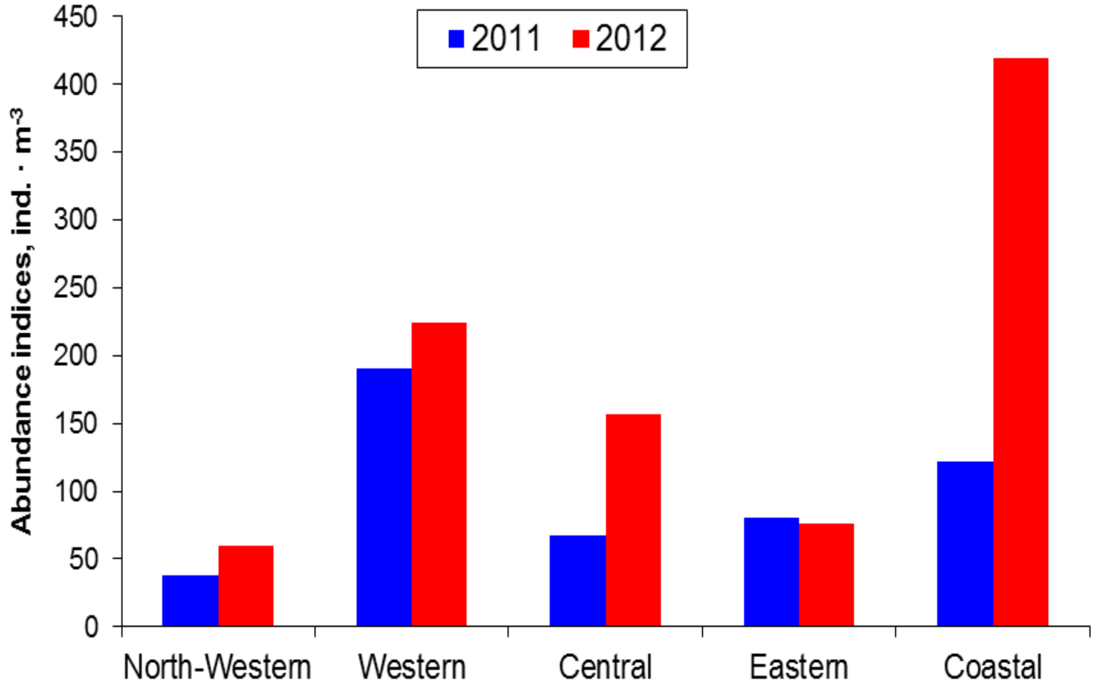


Figure 4.3.9. Mean abundance indices (ind. · 1000 m^{-3}) of *Meganyctiphanes norvegica* in North-Western, Western, Central, Eastern, and Coastal areas of the Barents Sea.

4.3.3.3 Gelatinous zooplankton

Figure 4.3.10 shows the distribution of gelatinous zooplankton taken in pelagic trawls during 2012 and 2013. Estimated abundance of large gelatinous zooplankton was higher in 2013 than in 2012. The center of distribution and highest abundance was located in the central to south-western part of the Barents Sea in 2013; a quite typical pattern consistent with observations from 2008 until present. During this period, occurrence of "jellyfish" has overlapped significantly with regions of low mesozooplankton biomass. In 2013, the average gelatinous zooplankton biomass was 34.41 kg·trawldistance^{-1} near twice the average estimated for 2011 (18.6 kg·trawl distance^{-1}). It is interesting to note that mesozooplankton biomass in 2013 was the lowest recorded since 1992, which may suggest a predator-prey relationship between these two groups of plankton. The data should however be interpreted with caution since many smaller "jellyfish" species are not sampled adequately with the method currently used.

The majority of hauls taken were standardized stepwise at 40-20-0m depth intervals, but a few were taken at greater depths. The catches were adjusted for length of trawling time.
It is assumed that results mainly reflect the occurrence of larger Scyphozoan medusa as in the genus *Aurelia* and *Cyanea*. The occurrence and proportion of Ctenophora ("comb-jellies") cannot be verified; they are largely absent due to rates of escapement and rough treatment in the trawl. Proper taxonomic classification is also an issue. Both *Ctenophora* and smaller "jellyfish" are however caught in the WP2 net, but this gear type has limitations due to the small volume sampled. Initial trials using a larger vertically operated WP3 net (UNESCO, 1968) have been initiated, and will likely be used in the future.

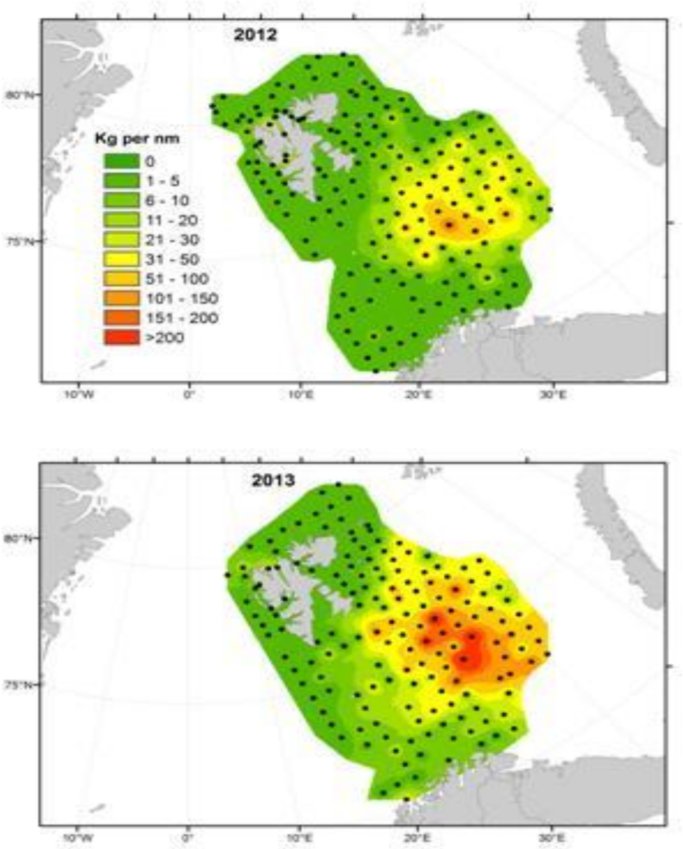


Figure 4.3.10. Distribution of gelatinous zooplankton based on pelagic Harstad trawl catches in 2012 and 2013. Numbers are standardized to kg·trawl distance^{-1}.

Expected situation

During August and September of 2013 in the Norwegian sector of the Barents Sea, the average mesozooplankton biomass was clearly below the long-term average. During 2008-2012 in this region, estimates of average biomass were relatively stable and slightly above 6.0 g dry weight m^{-2}, although the 2012 Norwegian data was less certain than in previous years. In 2013, highest mesozooplankton biomass in the Norwegian sector was observed north-east of Svalbard and in Atlantic Water masses in the south-west — where transport of zooplankton from the Norwegian Sea into central and western parts of the Barents Sea occurs. The continued lower-than-average biomass of mesozooplankton in the Norwegian sector of the Barents Sea suggests that also in 2014 initial conditions for local production there will largely be suboptimal; also, the overwintering population will likely be lower than observed in previous years.

In retrospect, there was considerable decline in abundance of euphausiids in the southern Barents Sea during 2009-2010, probably associated with increased consumption by capelin. The abundance of pre-spawning euphausiids by early 2011 is estimated to be 1.2 times above the long-term mean in the southern Barents Sea and 1.3 times above the long-term mean in the north- western Barents Sea. From 2011 to 2012 there has been a consistent increase in *Meganyctiphanes norvegica* in the western-, central and coastal areas, while *Thysanoessa inermis* account for most of the increase in the northwestern area. Hence, it is likely that during 2013-2014, advection and population abundance for *M. norvegica* — an Atlantic warmth-loving euphausiid species — will remain at a levels comparable to those observed during 2012. A similar pattern is predicted for the *T. inermis* population. The short term prediction for water temperatures in the Kola section is a slight decrease during 2014, which may help maintain a reasonable population level for arcto-boreal *T. raschii* in eastern areas — as this species seems to prefer shallow shelf regions and colder, less saline coastal water.

The long-term general warming trend, and further decrease in the extent of winter sea ice, will continue to facilitate expansion of warm-water species towards northern and eastern regions of the Barents Sea. Evidence of this expansion is seen in finding considerable amounts of euphausiids in the stomach contents of capelin north of Svalbard in 2007, and in the stomachs of both capelin and polar cod in the central and eastern Barents Sea during recent years. Recent findings of juvenile euphausiids north of 78ºN, and the regular occurrence of high krill biomass in north-west and south-east regions of the Barents Sea, support the belief that krill are expanding their range in the Barents Sea, due either to local recruitment (*T. inermis* and *Thysanoessa raschii*), or to the inflow of Atlantic Water masses and accompanying advection of more southerly species (*M. norvegica*, *Thysanoessa longicaudata*, and *Nematocelis megalops*). The increasing occurrence of Atlantic krill species during the last 10 years illustrates their expansion northward into the Barents Sea. It is less certain, however, just how these species will interact with other more firmly-established species, and whether they will be able to reproduce successfully and complete their life cycles in the new areas they populate.

The current below-average level of mesozooplankton biomass in the Barents Sea is probably linked to high capelin biomass. Other plankton consumers such as 0-group herring, cod, haddock, and redfish also have an important influence on zooplankton biomass. This was likely the case during 2013 when 0-group cod, herring, and haddock all had strong year classes; whereas capelin year-class size was closer to the long-term average. Total biomass of the four most abundant 0-group fish stocks (cod, haddock, herring, and capelin) reached 2.7 million metric tons. Capelin biomass alone was estimated to be 3.9 million metric tons during August-September 2013. It follows that predation pressure on zooplankton from numerous 0-group plankton consumers was considerable during autumn 2013. It is possible that conditions for lower-trophic-level production were above average, despite the low levels of mesozooplankton biomass. If so, this may have prevented mesozooplankton biomass from being reduced to even lower levels.

Gelatinous zooplankton, such as medusa (jellyfish) and ctenophores (comb jellies) are also believed to be important predators on mesozooplankton in the Barents Sea, but their influence is difficult to assess quantitatively. It should be noted, however, that the low mesozooplankton abundance in the central Barents Sea during August-September to a large extent coincided with high abundance of gelatinous zooplankton; this has been observed each year from 2010 to 2013, but was particularly evident during 2013. How this may link to the distribution of capelin and its consumption of mesozooplankton is not known. Gelatinous zooplankton and capelin may prefer different size spectra of zooplankton and fish larvae as prey items. If so, their diet overlap would be smaller, and their impact on each other as competitors may be smaller. Nonetheless, for gelatinous zooplankton in the Barents Sea, there is limited information on their preferred prey or the size spectrum of organisms they prey upon. Also of note, there are a range of carnivorous zooplankton competing with pelagic fish and jellyfish to prey on the basically herbivorous mesozooplankton. Their impact is largely uncertain, but the samples from the Norwegian WP2 >2000 um size fraction during 2013 (not shown) could be useful to help indicate the biomass of this carnivorous component. Current biomass of this size fraction is the lowest in the 1988-2012 time series, most likely due to high predation from pelagic fish, poor recruitment, or unfavorable feeding conditions, i.e., low availability of preferred prey.

Based on our current understanding of hydrographic conditions and long-term dynamics of zooplankton development, we expect spawning of copepods and euphausiids to begin in mid April in the south-western areas of the Barents Sea. Having overwintered, these groups of crustaceans, along with the warm-water species which have been transported from the Norwegian Sea, will create a zone with high density of zooplankton in north-western and western parts of the Barents Sea. In recent years a region with elevated zooplankton biomass, extending north- and southward, has been observed west of Novaya Zemlya in the Russian sector. This region had high mesozooplankton biomass during 2009-2011, albeit these levels were lower than observed during 2008. Levels again increased in 2013. This seems to be an area where herbivorous zooplankton (in certain situations or during certain years) are able to sustain viable populations and avoid excessive predation during summer and autumn, making it an important area for overwintering and re-establishing the population the following spring.

The high biomass of mesozooplankton found south to south-east of Franz Josef Land in 2009 and 2010 appears to have been reduced by 2011. During 2013, however, this region regained its high biomass, extending beyond what has been observed earlier. This was caused, in part, by an extended area of survey coverage in 2013. This area partially overlaps with distributions of capelin and polar cod in the north-eastern part of the Barents Sea, suggesting that predation from these two species on zooplankton could be large. At the time of the 2013 survey, however, 2013 the effect of such predation seemed insignificant. Relatively low zooplankton biomass in central parts of the Barents Sea appears to be a recurring phenomenon. This may result from heavy predation by capelin stock and other key 0-group fish species; gelatinous zooplankton could also be important predators. Since the central Barents Sea is among the more shallow regions, mesozooplankton there have limited potential to reduce predation through vertical migration to deeper waters.

4.3.4 Benthos

P. Lyubin (PINRO), L.L. Jørgensen (IMR), N. Anisimova (PINRO), and P. Renaud (APN).

<u>Recommendation given by IMR-PINRO for long-term monitoring of megafauna</u>

- Entire Barents Sea: Follow and report on a possible northward shift in commercial bottom trawling.
- Southwestern Barents Sea: Identify and protect bottom-trawl free areas which have been established to avoid catching *Geodia* sponges.
- Central Western Barents Sea (west of Svalbard): Establish bottom-trawl free areas to protect fields with high concentration of basket stars (*Gorgonocephalus spp.*), and sea lilies (*Heliometra spp.*).
- Northern Barents Sea (north of 80ºN): Protect shelf and slope areas from all types of bottom trawling where high concentrations of the sea pen (*Umbellula encrinus*) are recorded.
- Central Barents Sea: Closely follow benthic communities as snow crab (*Chionoecetes opilio*) distribution widens to evaluate impacts of predation by snow crabs.
- Eastern Barents Sea: Follow and report on possible effects of the snow crab (*Chionoecetes opilio*) on benthic megafauna.
- Entire Barents Sea: Follow and report on the borealisation of the megafauna particularly along the benthic polar front (Hopen Deep).

4.3.4.1 Spatial distribution of benthos

More than 3,050 invertebrate species inhabit the Barents Sea benthos (Sirenko, 2001) and boreal-arctic species dominate in terms of biomass.

Benthic areas with low abundance (less than 1,000 individuals/ m^2) and low biomass (less than 10-25 g/m^2) are usually restricted to bottom depressions such as western deep-water areas in the Bear Island Channel (Bjørnøyrenna) and Hopen Deep (Hopendypet) (Figure 4.3.11), deep-water areas between Franz Josef Land and shallow waters of the Novaya Zemlya Bank, and deep-water areas in the Eastern Basin (Øst bassenget sør) (Figure 4.3.11). Areas with high biomass (biomass hotspots) — holding rich communities dominated by epifauna suspension feeders — are usually located in areas with elevated in sea-floor topography, coarse substrates, and strong currents (Kiyko and Pogrebov, 1997a).

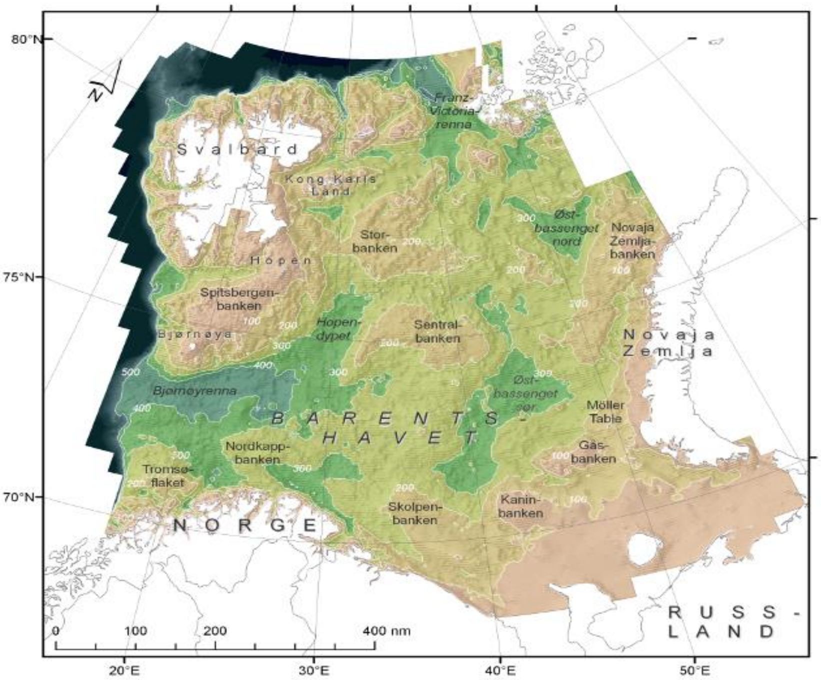


Figure 4.3.11. Barents Sea bottom topography.

Distribution of zoobenthic organisms in the Barents Sea is related to depth, near-bottom temperature, sediment type (Dahle et. al, 1998; Denisenko, 2007), and — perhaps most importantly — food availability and abundance (Wassmann et al., 2006; Denisenko, 2007; Carroll et al., 2008). Cochrane et al. (2009) observed that infaunal density (mostly worms and bivalves) and species richness were 86% and 44% greater, respectively, at stations located near the Polar Front, compared to stations located in either Atlantic- or Arctic-dominated water masses; this pattern is consistent with reports of elevated primary production at the Polar Front (Carroll et al., 2008). In Arctic Water(s) north of the Polar Front, ice cover suppresses water column productivity and infaunal abundance was significantly lower compared to waters south of the Polar Front, while the numbers of taxa present were similar. In contrast, biomass of epifauna (mostly brittle stars, sponges, and shrimp) was more than 5 times greater in the northern Barents Sea compared to communities influenced by Atlantic Water(s) (Jørgensen et al 2015). A species of basket star (*Gorgonocephalus arcticus*) dominating the northern ice covered areas, is a predatory suspension-feeder that consumes krill and other pelagic crustaceans (Emson et al., 1991). In this area mass occurrences of

Arctic-endemic brittle stars have been found in several studies (Piepenburg and Schmid, 1996b; Piepenburg, 2000; Ambrose et al., 2001).

Another biomass-hotspot is found in the southwestern area of the Barents Sea, characterized by: inflow of warm Atlantic Water with relatively high primary production; strong water currents which re-suspend food material; and hard bottom substrate that supports sessile filter-feeders (Wassmann et al., 2006; Hunt et al., 2013). Biomass in this area is dominated by the *Geodia* genus of sea sponge (Jørgensen et al., 2015).

Brotskaya and Zenkevich (1939) defined six main areas with macrozoobenthos communities in open waters of the Barents Sea (Figure 4.3.1 2). The southwestern Barents Sea (I, red, Figure 4.3.12) was characterized by high abundance of boreal species and predominance of seston-feeders. The central Barents Sea (II, light blue, Figure 4.3.12), at an average depth about 200 m and on sandy silt, had a rather low biomass compared to other communities; species composition was very homogenous and dominated (in biomass) by 4 species, including: the polychaete (*Spiochaetopterus typicus*); the bivalve (*Astarte crenata*); the deposit-feeding sea star (*Ctenodiscus crispatus*); and the large sipunculid (*Golfingia margaritacea*). In eastern and southeastern parts (III, green, Figure 4.3.12) complex communities inhabiting silty and sandy sediments at depths less than 200 m were characterized by rather high benthic biomass with bivalve mollusks accounting for (on average) half of the total benthic biomass. *Astarte borealis*, *Macoma calcarea*, and *Ciliatocardium ciliatum* were predominant bivalve species in these communities.

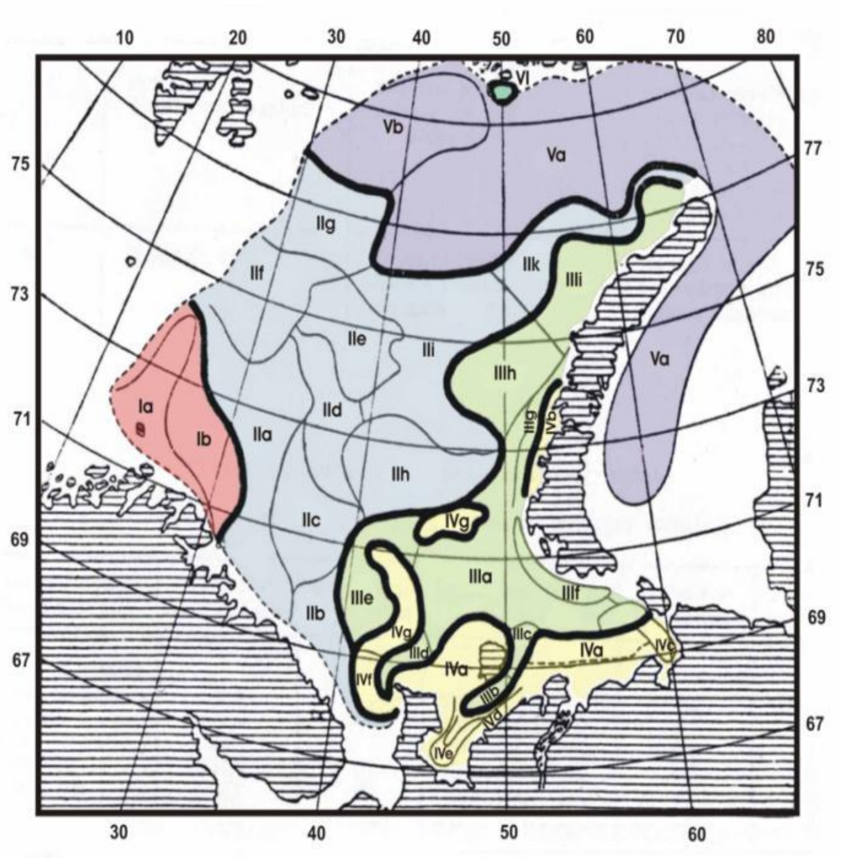


Figure 4.3.12. Distribution of bottom area complexes according to benthic surveys from 1924-1935 (after Brotskaya and Zenkevich 1939). The name and details of the area complexes are given in the text (Source: PINRO).

In the eastern and southeastern coastal area (IV, yellow, Figure 4.3.12) communities occurred on sandy bottoms in shallow coastal waters of the Pechora Sea, and along the coasts of Novaya Zemlya and Franz Josef Land. Bivalve species (*Astarte borealis*, *Macoma calcarea*, and *Serripes groenlandicus*) and the sea squirt (*Pelonaia corrugate*) burrowed in the sand and formed the predominant biomass in this community. The biomass of coastal communities was slightly lower than in open waters in the southeastern part of the Barents Sea, but was quite high relative to other regions.

The Northern community (V, dark blue, Figure 4.3.12) is situated in the northern part of the Barents Sea on brown soft mud at 200-450 m depth. Low biomass and a high percentage of Arctic deep-water species are typical for this complex. Large Arctic ophiurids, e.g., *Ophiopleura borealis*, the large dolioform sea-cucumber *Molpadia* (at some stations), and the bivalve mollusk (*Astarte crenata*) are predominant here. Finally, the Northern Barents Sea Shallow Water community (VI, white, top of Figure 4.3.12) is situated at 100 m depth in the Franz Josef Land archipelago on sandy sediment with stones. This community is predominance by epifauna of relatively high biomass. Communities with a similar complex of dominant species were singled out in the shallow waters of Svalbard. Two species of bivalve molluscs (*Hiatella arctica* and *Astarte borealis*), barnacles of genus *Balanus*, and the polychaete (*Thelepus cincinnatus*) are predominant. All these species are seston-feeders; hence, this complex is typical for shallow waters with active hydrodynamics.

Jørgensen et al. (2015) characterized areas of the Barents Sea based on the dominance of megafauna sampled in 2011 (Figure 4.3.13). The south western Barents Sea (SW) was dominated by large-bodied *Geodia* sponge species. *Geodia*, together with other sponge species, also dominated the continental slope north towards Svalbard, and the outer Bear Island Channel and North Cape Bank into the Barents Sea. In the deeper Bear Island Channel, the sea star (*Ctenodiscus crispatus*), and the sea cucumber (*Molpadia borealis*) dominated in biomass.

Along the coasts and within fjords and sounds of western and northern Svalbard, diverse echinoderm fauna occurred, including: *C. crispatus*; *Ophiura sarsi*; *Strongylocentrotus* spp.; *Icasterias panopla*; and *Gorgonocephalus arcticus*.

At shallow Spitsbergen Bank in the west, on slopes of Kolguyev Island and Novaya Zemlya, on Goose Bank, and on Kap Kanin Bank in the southeast (SE) dominant filter feeders found were bivalves (*Chlamys islandica*), and sea cucumbers (*Cucumaria frondosa*). Many locations in the southeast (SE) were populated by the non-indigenous and highly predatory snow crab (*Chionoecetes opilio*); red king crab (*Paralithodes camtschaticus*) occurred near the coast.

In the northwest region — Hopen Deep, Storfjord Trench, and banks south of the Central Bank — *C. crispatus* and *M. borealis* were dominant species. Further north on the shallow and cold Central Bank, on the slopes of the Great Bank, around Kong Karls Land, and in areas east of Svalbard, the detritivore *Strongylocentrotus* spp. dominated along with

Gorgonocephalus eucnemis and the sea lily (*Heliometra glacialis*). Associated fauna in these localities were sea stars (*Icasterias panopla*) in Hopen Deep, *Urasterias linkii* on banks and slopes, and the crustacean (*Sabinea septemcarinata*).

The northern part of the NE region (Figure 4.3.13) had almost year-round ice coverage and several species of sponge dominated together with large aggregations of brittle stars (*Ophiopleura borealis* and *Ophiacantha bidentata*). In the southeastern basin and areas next to Goose Bank, snow crabs dominated the shallowest areas, together with *Strongylocentrotus* sp. and *Sabinea septemcarinata.* Snow crabs also dominated in the deeper areas; together with *Spiochaetopterus typicus* and sea cucumbers (*M. borealis*). Further north in the deep St. Anna and Franz-Victoria Troughs, sea-pens (*Umbellula encrinus*) dominated in biomass.

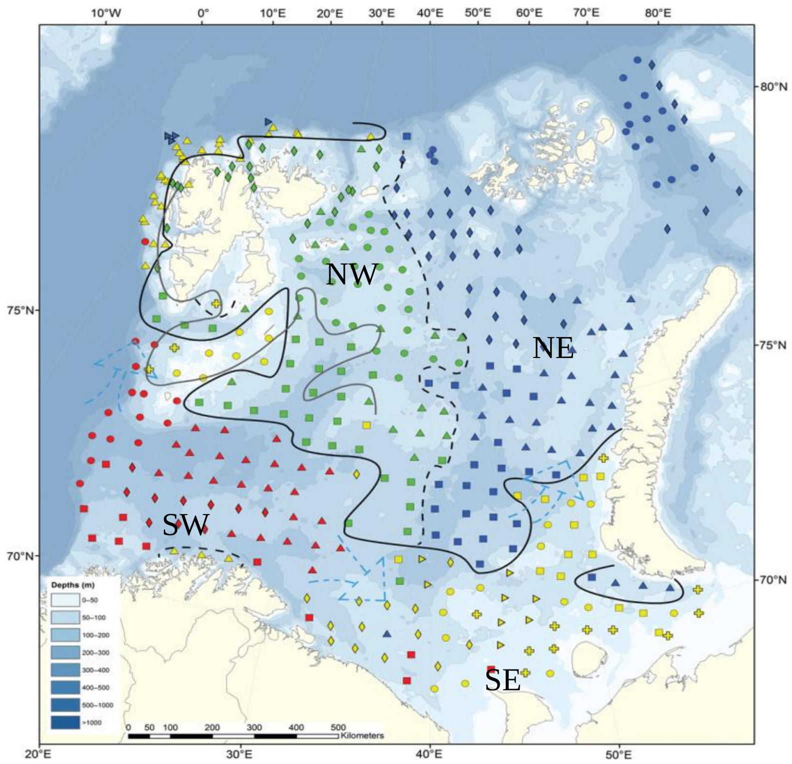


Figure 4.3.13. Distribution of station clusters in northern (green and blue) and southern (yellow and red) regions of the Barents Sea. The continuous black line marks the approximate north-south division illustrating the "benthic Polar Front". The continuous grey line marks the approximate oceanographic Polar Front. The (almost) vertical dotted line divides the northern Barents Sea into western and eastern parts. (Source: Jørgensen et al 2015).

Temporal changes in the distribution of benthic abundance and biomass

A decline in total biomass of benthic fauna has been observed from 1924-1935 to 1968-1970 (Antipova, 1975) (Figure 4.3.14); this decline occurred almost throughout the Barents Sea. Many investigators attributed the reduction in biomass to climate change, although the contributing mechanisms are not clear. Some studies suggest that it was due to a change in faunal distribution during the cold period between the 1960s and 1980s (Bryazgin, 1973; Antipova, 1975; Bochkov and Kudlo, 1973) (Figure 4.3.15). Others make reference to declining biomass of resident boreal-arctic species during the 1930-1960 warming period (Galkin, 1987; Kiyko and Pogrebov, 1997a, 1998). Dominant boreal-arctic species have an optimum temperature range falling within the long-term mean temperature for the region. According to this latter theory, any deviation from the long-term mean would have a negative impact on boreal-arctic species reproduction, abundance, and biomass (references in Anisimova et al., 2011).

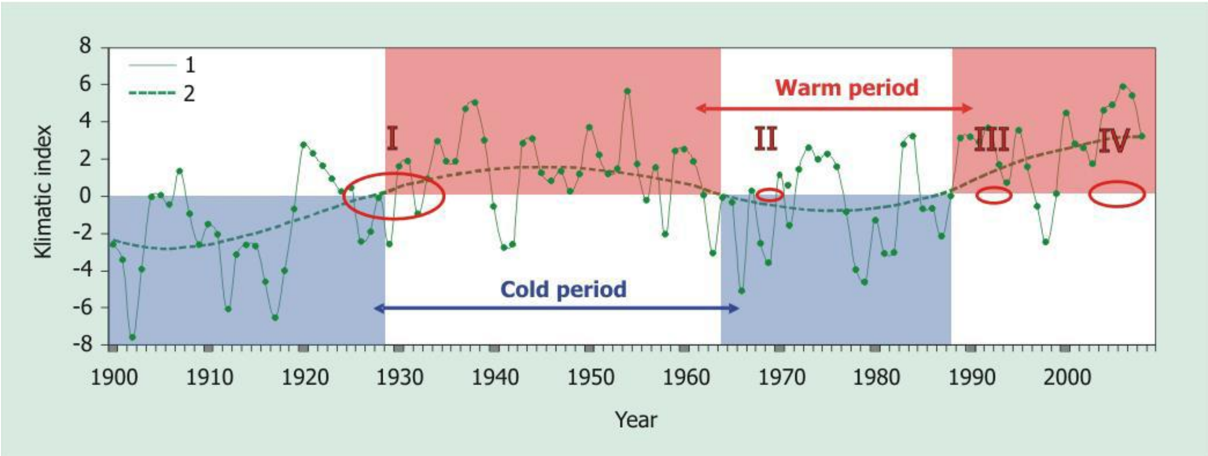


Figure 4.3.14. Inter-annual changes in climatic index (reflecting the cumulative variability of major climate indicators such as sea and air temperature and ice coverage) in the Barents Sea (1), and its quasi-secular cycle (2) (Boitsov, 2006). The periods of four main quantitative benthic surveys are shown within red circles (Source: PINRO).

Surveys conducted during 1924-1935 and 1991-1994 followed long cold periods with a predominance of negative temperature anomalies. Estimates of total benthic biomass did not differ significantly between these two survey periods; they did, however, exceed benthic biomass estimated after the 1968-1970 warm period (Kiyko and Pogrebov, 1997a).

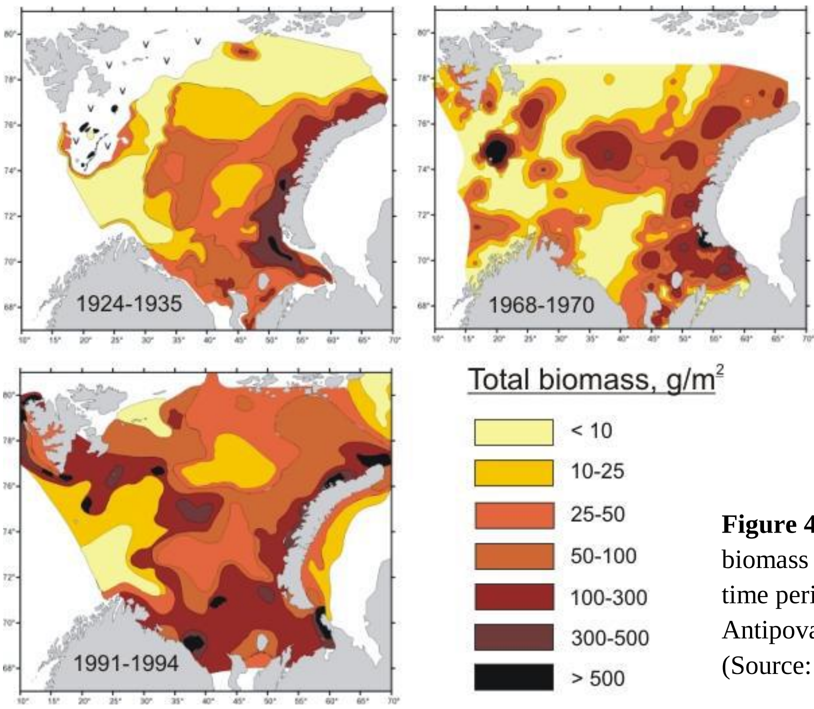


Figure 4.3.15. Distribution of the benthic biomass of the Barents Sea during different time periods (Brotskaya & Zenkevich, 1939 Antipova, 1975; Kiyko and Pogrebov, 1997 (Source: PINRO).

Denisenko (2001) suggested that reductions in benthic biomass — during the late 1960's and several other decades of the 20th century — were related to intense bottom trawling more than to temperature fluctuations. This suggestion was built upon work showing that benthic biomass was twice as high during World War II, when the Russian fishery was essentially closed, compared to other periods when trawling took place.

Megabenthic faunae have been monitored using fishing trawl gear (Campelen 8000) since 2005 (Anisimova et al., 2010; Anisimova et al., 2011; Jørgensen et al., 2015). These organisms represent the large-bodied fraction of the benthos, such as sea stars, crabs, and corals. In the Barents Sea, a steady increase in the number of species was recorded between 2005 and 2013 (Figure 4.3.16). This is partly due to development of a benthic-expert exchange program between Russia and Norway to collaborate and share knowledge onboard research vessels to improve species identification keys. Standardized species nomenclature is maintained by using this core of benthic expertise, common literature sources, and internationally recognized databases of accepted names (i.e., WoRMS, OBIS).

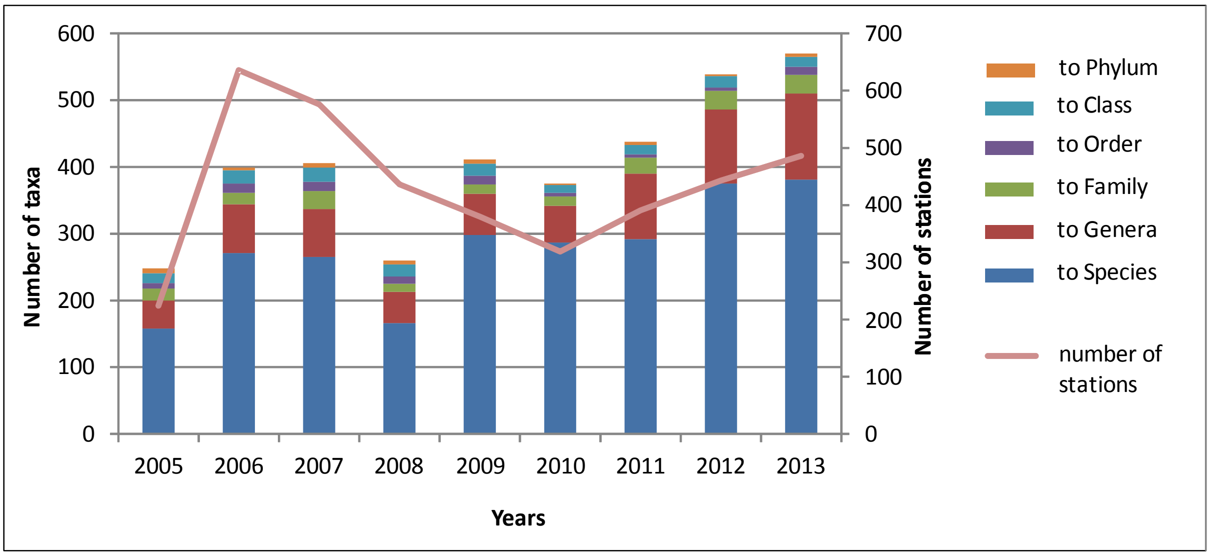


Figure 4.3.16. Number of megabenthic taxa (left axis) recorded in the Barents Sea during the annual IMR–PINRO ecosystem surveys during 2005-2013 (horizontal axis). The taxa are identified to (from the top) Phylum (orange), Class (light blue), Order (purple), Family (green), Genera (red), and Species (blue). Full line - number of stations covered (right axis).

The average biomass of megafauna in a standard 15-minute Campelen trawl tow remained stable (between 30-40 kg) between 2006 and 2011 (Figure 4.3.17). In 2012, biomass increased several fold, due to altered construction of the Campelen bottom trawl on one of the ships participating in the Joint Ecosystem Survey. In 2013, the biomass estimate was generally higher than the long-term mean.

Regardless of the survey year, high biomass was observed in the cold water along the south and west coasts of Novaya Zemlya (Porifera, *Strongylocentrotus* sp., *Chionoecetes opilio*, *Sabinea septemcarinata*), at (the Atlantic water influenced) Spitsbergen Bank (*Cucumaria frondosa*, *Chlamys islandica*, Porifera indeterminate, *Hyas* spp., *Leptasterias* sp.), and the south-western Barents Sea (*Geodia* sponge field) (Figure 4.3.18); while the central-southern Barents Sea had the lowest biomass and abundance.

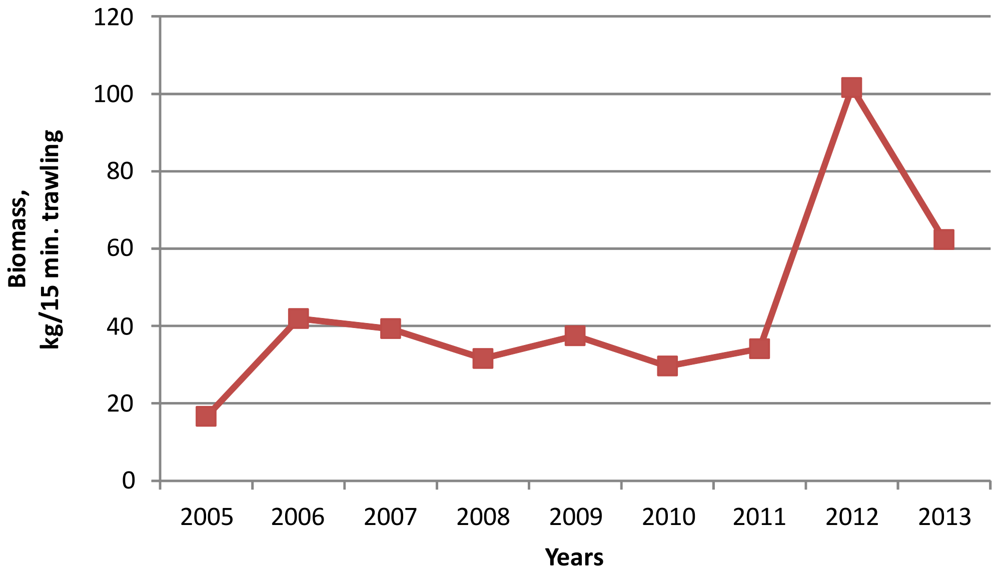


Figure 4.3.17. Fluctuations in total average biomass of benthic megafauna for standard 15-minute trawl hauls during the period 2005–2013. For number of stations per year see figure above.

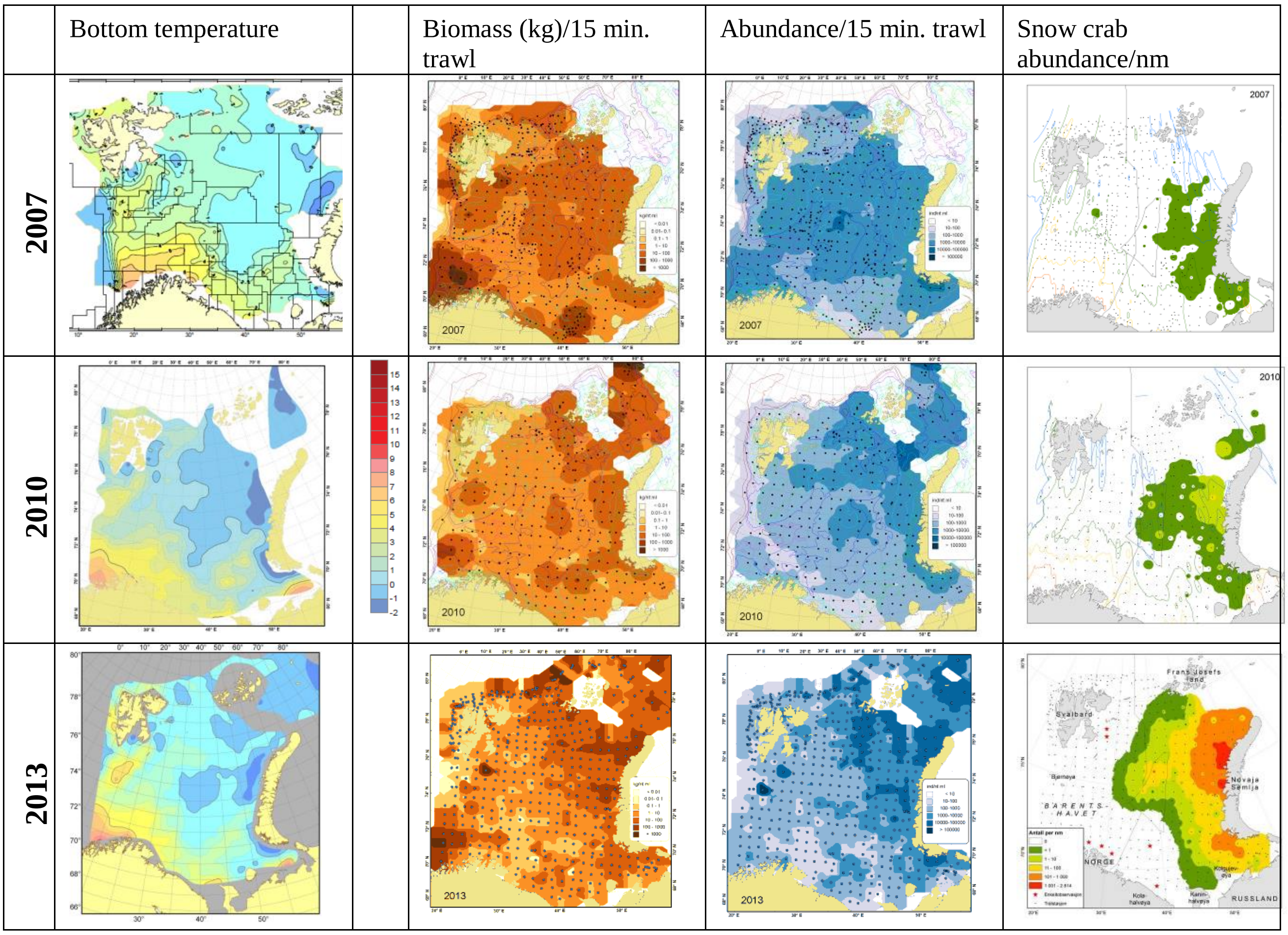


Figure 4.3.18. Bottom temperature, biomass, abundance of megafauna, and abundance of snow crab in the Barents Sea in the period 2007-2013.

A general decrease in biomass and abundance has been observed north of Varanger Peninsula inside the Russian Barents Sea; minimum values were observed in 2013 — less than 1 kg of biomass and 100 individuals per 15-minute trawl. Temperatures in this zone tend to fluctuate between 2 – 4 ºC, depending on the inflow of warm water from the Norwegian Sea. Whether the reductions in biomass and abundance are due to temperature variation, other natural causes, or human pressures is not well understood at present; further studies are needed to reveal possible impacts.

High biomass was recorded in 2007 northwest of Kap Kanin and further east along the coastline (Figure 4.3.18). This was due to spreading distribution of red king crab (*Paralithodes camtschaticus*); the densest concentrations were observed in 2008 (more than 500 ind./sq.km). This species was deliberately introduced from the northern Pacific Ocean into several location of the Barents Sea during the 1960s and 1970s (Olav and Ivanovo, 1978). It has continuously spread into new areas and is currently distributed from Kluge Island in the east, to Goose Bank in the north, and westward to Lofoten and Kvænangen along the Norwegian coast. Several studies reveal that, besides being an important fishery resource, this crab species significantly impacts benthic ecosystems when it occurs at high densities (Jørgensen, 2005; Jørgensen and Primicerio, 2007; Oug et al., 2011). In Russian waters of the Barents Sea, red king crabs occur from shallow waters to depths below 335 m, at temperatures ranging from -0.8 to +8.5ºC. Red king crabs are benthic predators (Gerasimova and Kachanov, 1997; Manushin, 2003); but in areas with intensive fishing, they feed predominantly on fish offal (Pinchukov and Pavlov, 2002; Anisimova and Manushin, 2003). The main species preying on red king crabs are cod, wolffish, and skates (Matyshkin, 2001), but only during the crab's juvenile stages (Falk-Petersen et al., 2011).

In the eastern Barents Sea, both biomass and abundance of benthic organisms increased in 2013 (Figure 4.3.18). This may, in part, be explained by a steadily increasing snow crab (*Chionoecetes opilio*) population: estimates of mean abundance and biomass in 2007 (2.3 ind. and 356 g/15 min. trawl); were higher in 2010 (8 ind. and 396 g/15 min. trawl); and had increased dramatically by 2013 (153 ind. and 9058 g/15 min. trawl). Snow crab observations were first recorded in the Barents Sea during 1996, close to northern Goose Bank (Kuzmin, 2000). Preliminary results from DNA finger-printing (K. Jørstad, IMR, pers. comm.) indicate that spreading originated east of the Barents Sea. The Ecosystem Survey has documented spreading from eastern to western parts of the Barents Sea. As the snow crab is a cold-water species living at depths from 20 to 700m, at temperatures below 5 to 8C (Elner and Beninger, 1992), its distribution is expected to increase and spread over most of the Barents Sea (Renaud et al., 2015). In 2010, smaller crabs were found exclusively on Goose Bank, indicating that this is a recruitment area (Agnalt et al., 2011). Warming might push the snow crab further north, allowing this species to become established in waters surrounding Svalbard and Franz Josef Land. In its wake, the snow crab will have considerable impact upon its epibenthic prey species, including: polychaetes, northern prawns (*Pandalus borealis*), brittle stars, gastropods, other crabs, and sea urchins (Squires and Dawe, 2003).

Arctic – Boreal species distribution

Results from the 2009 and 2013 Joint Ecosystem Surveys indicate that the only areas of the Barents Sea where Arctic species consistently do not occur, i.e. "Boreal areas," are southwestern and coastal areas in the southern region. In contrast, the only areas without boreal species, i.e. "Arctic areas," are the eastern area west and south of Franz Joseph Land and further south into the deep Eastern Basin (Figures 4.3.19 and 4.3.20). While the western Barents Sea is a transition zone with gradually lower dominance of boreal species proceeding northward. The southeastern Barents Sea has an abrupt division between these two zoogeographic areas in the transition from the deep Eastern Basin to the shallow Kanin- and Skolpen Banks.

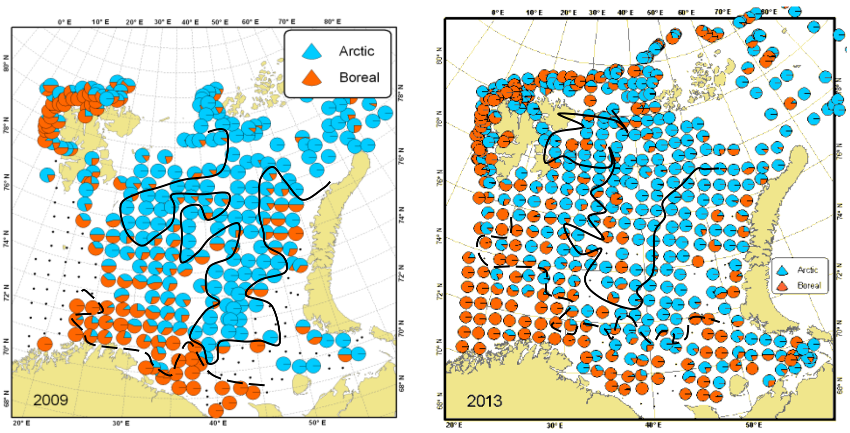


Figure 4.3.19. The Arctic (blue) and the Boreal (red) fraction of each station collected in 2009 and 2013. Boreal-arctic species are not shown.
The solid line marks the approximate area of Arctic species; the divided line marks the area of Boreal species.

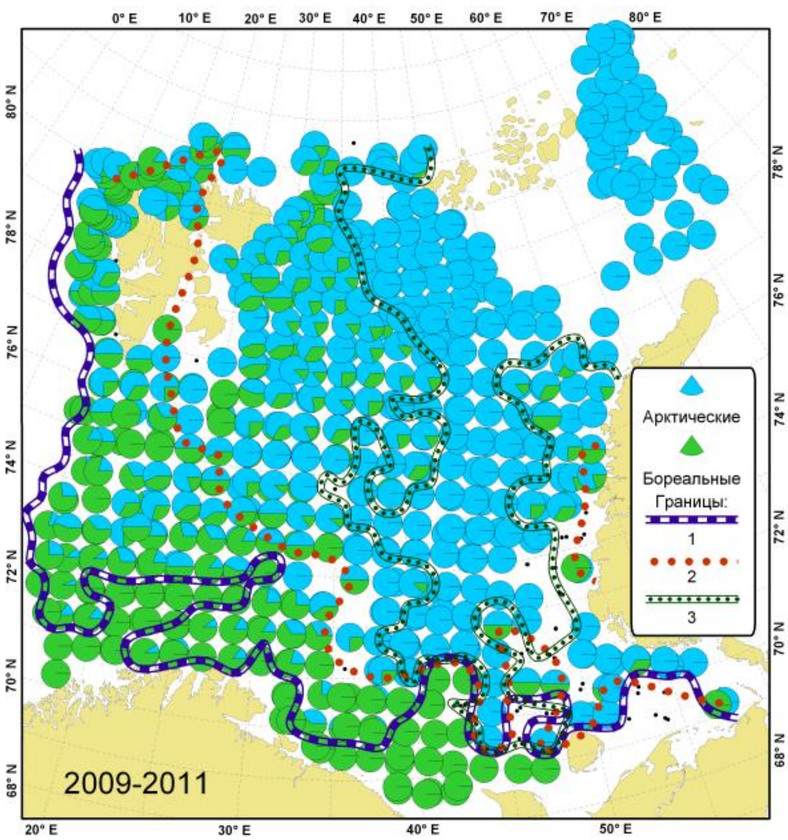


Figure 4.3.20. Biogeographic boundary for Boreal and Arctic megabenthos species integrated across the 2009-2011 period. Data collected during the Joint Russian-Norwegian Barents Sea Ecosystem Surveys (PINRO / IMR).

Blue: Arctic species
Green: Boreal species

Line 1 - border for Arctic species distribution.
Line 2 - 50% ratio of Boreal and Arctic species.
Line 3 - boundary for Boreal species.

As a general trend, a border with “50% Boreal and Arctic species” can be drawn from north of Svalbard, through the Hinlopen Strait, across Svalbard Bank, and southward along the west side of the Central Bank, and along shallow areas into the Pechora Sea in the South Eastern Barents Sea (Figure 4.3.20, red dotted line). This line also shows the abrupt zoogeographic change in the southeast where the Arctic and the Boreal areas meet geographically.

4.3.4.2 Effects of fisheries on benthos

Recent ocean warming has caused some commercial fish species to expand northward. This includes the Atlantic cod (*Gadus morhua*), which has recently been recorded north to 82ºN on the edge of the Barents Sea shelf to the Arctic Ocean (Johansen et al., 2013; Kjesbu et al., 2014). As a consequence, the commercial trawling fleet may follow this stock to more northern parts of the Barents Sea, e.g. from the Hopen Deep, to formerly ice-covered areas previously too cold for predominantly boreal fish species such as Atlantic cod.

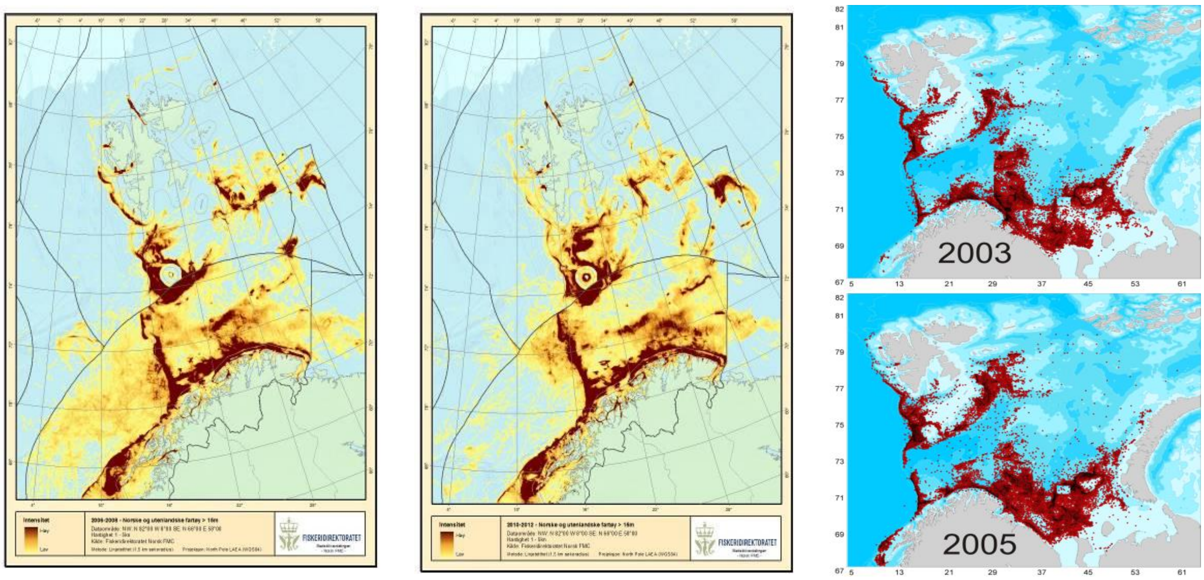
Bottom trawling, suggested to be the equivalent of forest clear-cutting on land (Watling and Norse, 1998), is known to have significant and potentially long-lasting impacts on seafloor communities. Impacts include: removal of habitat-forming organisms; homogenization of seafloor habitats; altered sediment structure; and reduced oxygen penetration into the sediments (e.g. Collie et al., 2000; Thrush and Dayton, 2002; Kaiser et al., 2006). It can affect benthic megafauna, particularly erect sessile forms which are fragile and easily damaged or destroyed by bottom trawls (Kaiser et al., 2002; Hiddink et al., 2006). Frequent disturbance of soft-sediment communities leads to the proliferation of smaller benthic species with faster life histories. Because the larger species are usually removed by bottom-fishing gears, both habitat complexity and the depth of bioturbation are often reduced, resulting in lower benthic production (Jennings et al., 2001; Kaiser et al., 2006).

Specific functional groups of benthic organisms have been shown to be particularly sensitive to bottom trawling. These include emergent epifauna, some bioturbating decapods, suspensions feeders, and long-lived high-biomass organisms (including sponges and corals) (Garcia et al., 2007; Olsgard et al., 2008; and Mangano et al., 2014). Changes affecting such groups could have far-reaching ecosystem impacts and alter ecosystem services (fish nursery habitat, feeding grounds, biogeochemical cycling) provided by such components of benthic communities, including food-web interactions which support commercial fish and shellfish stocks (Widdicombe et al., 2004; Olsgard et al., 2008). Habitat-generating species are represented by a wide range of taxonomic groups (e.g. Porifera, Polychaeta, Cnidaria, Mollusca, and Bryozoa (Kaiser and de Groot, 2000) provide shelter for diversely associated species, and are examples of entire communities which require protection.

Studies indicate that between the 1920s and 1960s, benthic biomass in the Barents Sea declined by up to 70% in some areas (Denisenko, 2001). It is uncertain how much of that reduction is attributable to bottom fishing, but the correlation between spatial patterns of biomass reduction and fishing pressure is reasonably high (Figure 4.3.21). Some systems may recover from fishing activity, as was the case for Svalbard Bank after intense scallop dredging in the 1980s (Kędra et al., 2013). Such a recovery, however, may depend upon local hydrodynamics (affecting grain size and food supply) and the intensity of fishing pressure (Collie et al., 2000). Identifying a set of indicators to determine the impacts of trawling would be a huge step forward for benthic habitat management.

Megafauna and areas vulnerable to trawling

Fisheries in the Barents Sea are generally conducted in certain areas (Figures 4.3.21 and 4.3.22), but variations occur due to interannual fluctuations in commercial fish stocks (Figure 4.3.22). A slight northward expansion of fishing activity on the east side of Svalbard was observed during 2006-2008 and 2010-2012.



Trawling intensity 2006-08 (Source: www.fiskeridir.no/)

Trawling intensity 2010-12 (Source: www.fiskeridir.no/)

Russian trawling in 2003 and 2005 (source: PINRO)

Figure 4.3.21. Fishing activity in the Barents Sea 2003-2005 (Russian registered fishery), 2006-2008 and 2010-2012 (Norwegian registered fishery).

Bottom trawling is expected to capture large bodied megafauna (Jørgensen et al., 2014). When "mean body weight" (i.e., weight/abundance) and "height" was used as a proxy for vulnerable species, possible vulnerable areas were observed along the continental slope of the Barents Sea, in the Arctic northern and eastern Barents Sea, and in a narrow band in the south (Figure 4.3.22, left). In the central Barents Sea, particularly outer Bear Island Channel and the Pechora Sea in the south-eastern region, the megafauna consisted of relatively small individuals.

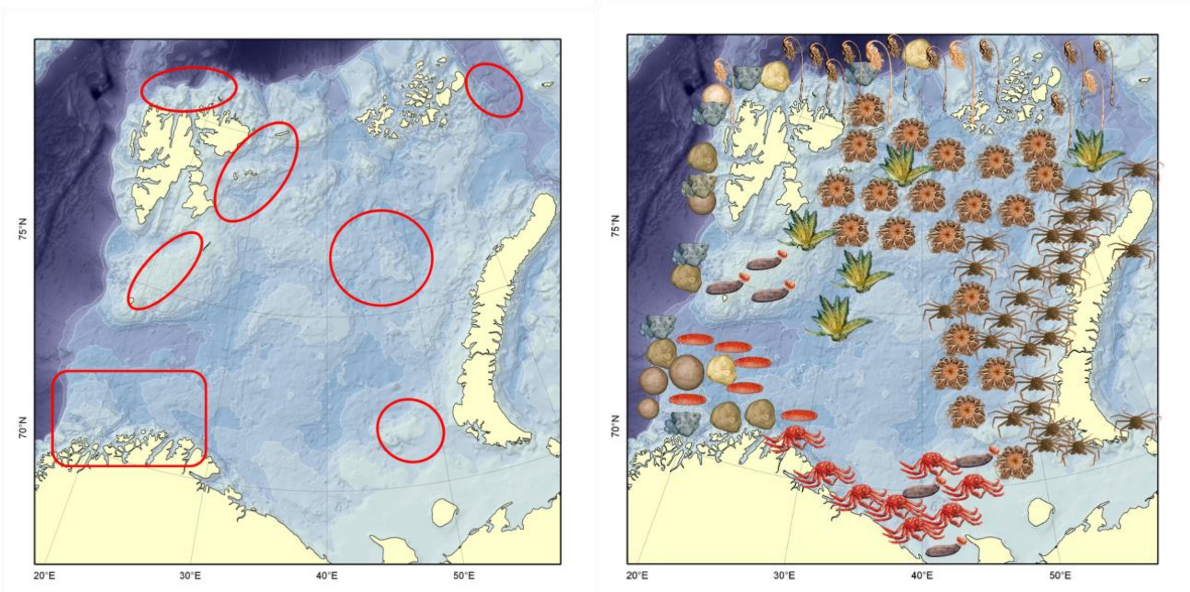


Figure 4.3.22. Particularly vulnerable areas (red circles, left side map), and distribution of large/voluminous and/or large upraised body-size species (right side map) easily taken by a trawl (Jørgensen et al., 2015).

Figure 4.3.22 (right) shows species easily taken by a trawl due to large and/or upraised bodies, which include:

- *Geodia* sponges distributed from the southwestern Barents Sea and northward along the continental shelf, round northern Svalbard and further east;
- King crab populations along the southern coastline;
- Sea cucumber populations on the Svalbard Bank and Banks in SE (*Cucumaria frondosa*), or the deep continental slope in SW (*Parasticopus tremulus*);
- Sea lilies along the shelf area of the banks and in the northern part of the Barents Sea.
- Snow crab populations
- *Gorgonocephalus spp.* with fields of basket stars covering vast areas in the north; and
- Sea pens (*Umbellula encrinus*) north of 80ºN.

All of these represent species and areas in possible need of protection against trawling (Jørgensen et al., 2015).

4.3.4.3 Multiple impacts on the megafauna

The Barents Sea is subjected to a number of pressures (Figure 4.3.23) which are expected to have an effect on the megabenthos. These pressures include: 1) the non-indigenous snow crab, which may become a dominant species in a continuously spreading zone; 2) the influx of warm Atlantic waters into southwestern and possibly northwestern regions which may change the balance of Boreal and Arctic species, and consequently the biomass, abundance, feeding type, and production of particular species; and 3) northward expansion of commercial fish stocks which may cause increased bottom trawling in northern areas.

We recommend continuation of the PINRO-IMR long-term monitoring program of the megabenthos to follow the footprints made by each of these pressures in potentially affected regions (Figure 4.3.23). Monitoring should also follow cumulative future impacts from snow crab expansion, temperature increase, and the effects of trawling, particularly in the central Barents Sea.

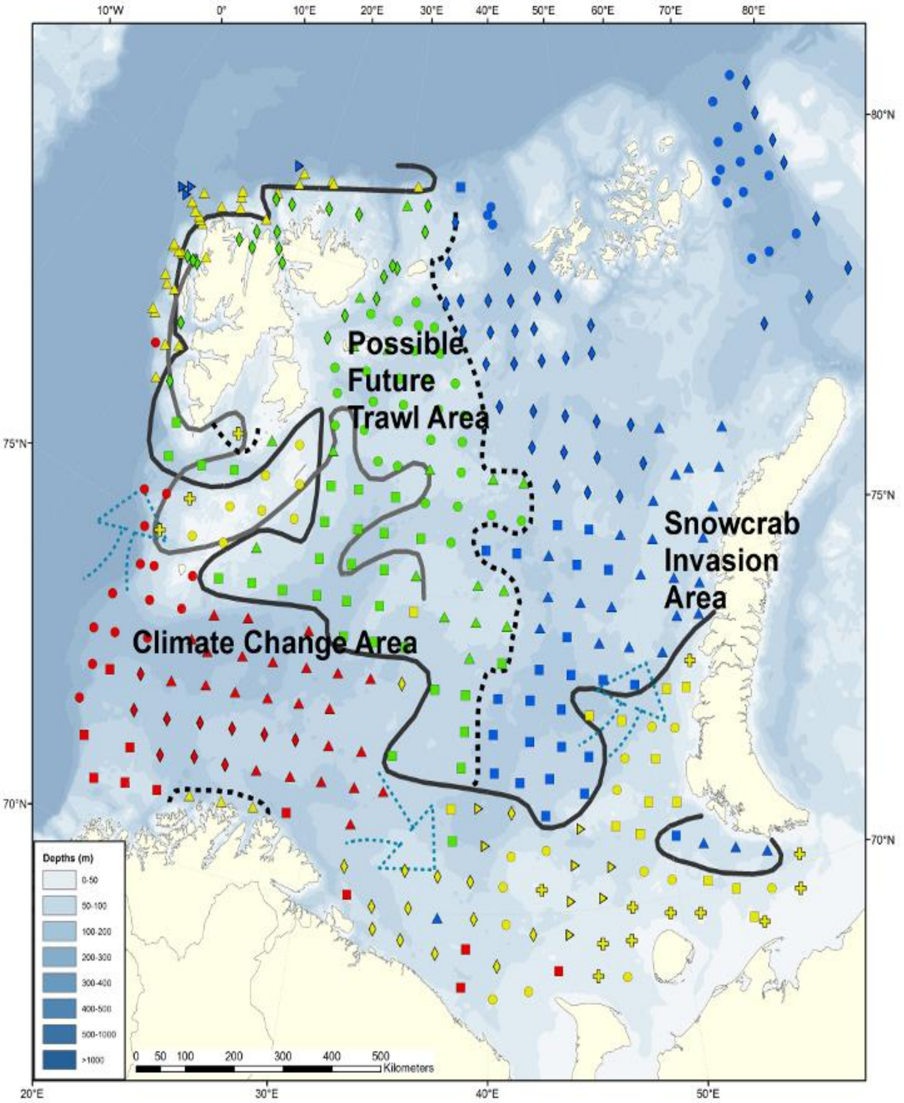


Figure 4.3.23. Multiple impacts in the Barents Sea: Increased inflow of warm Atlantic water, northward expansion of bottom trawling due to northward expansion of commercial fish stocks, spreading of snow crab from the east toward the west.

We suggest defining a set of “Ecological Objectives for Benthos in the Barents Sea” (Table 4.3.1) to follow the ecological footprint from each of the defined pressures. Here we give examples of quality objectives and indicate trends observed during the 2007-2013 period.

Table 4.3.1. Suggested Ecological Objectives for Benthos in the Barents Sea. SW (south-western Barents Sea), NW (north-western Barents Sea), NE (north-eastern Barents Sea).

Quality Objectives	Results 2007-2013
• Density and spatial distribution of selected "large-bodied" species shall not decrease due to trawling.	• SW: stable biomass • NW: fluctuating biomasses/abundances. Need closer investigations. • NE: Seemingly stable biomasses/abundances but poor station coverage due to ice cover and remoteness
• Predation from snow crab on benthic megafauna shall not have impact on food availability for bottom-feeding fish.	• Follow the crustacean and echinoderm decreases in shallow areas • Look for other indicator species for other types of habitat
• A temperature induced change in megafaunal species composition shall be monitored and possible to distinguish from effect from snow crab and effect from trawling.	• A possible borealisation • A seemingly stable boreal zone in SW

4.3.4.4 Kola section: long-term zoobenthic monitoring

O. Lyubina (MMBI), N. Anisimova (PINRO), and P. Lyubin (PINRO)

Zoobenthic monitoring in the Kola section is one of the most published and extensive monitoring programs in the Russian Arctic. Data collection was initiated in the early 20th century by the Marine Biological Station, in Alexander Harbor of the Kola Bay. Modern benthic investigations in the Kola Section have been conducted by the Murmansk Marine Biological Institute (MMBI) since 1995. PINRO joined the monitoring program in 2003 using methods comparable to the existing long-term monitoring series. Since 2010, PINRO and MMBI have collaborated to ensure increased sampling regularity, greater speed in data processing, and more accurate taxonomic identification.

During the last 17-years (1995 - 2012), the annual monitoring program at the Kola transect has consisted of 9 surveys, including 410 samples taken at 87 stations. Throughout this period, benthic stations have been located along the Kola section (33°30' E) from 69°30' N to 74° N with a 30-minute trawling interval (Figure 4.3.24). During 1995, 2 grabs ("Ocean-50") were taken at each station covering a 0.25 m^2 sampling area. In all other years, data were collected using a "van Veen" grab covering a 0.1 m^2 sampling area. In optimal situations, 5 samples were collected as standard at each station. Until 2010, the samples were sieved through a 0.75 mm nylon mesh; since 2010, through a 1 mm mesh. Surveys have been conducted during 1995, 1997, 2000, 2001, 2003, 2007, and 2010 – 2012.

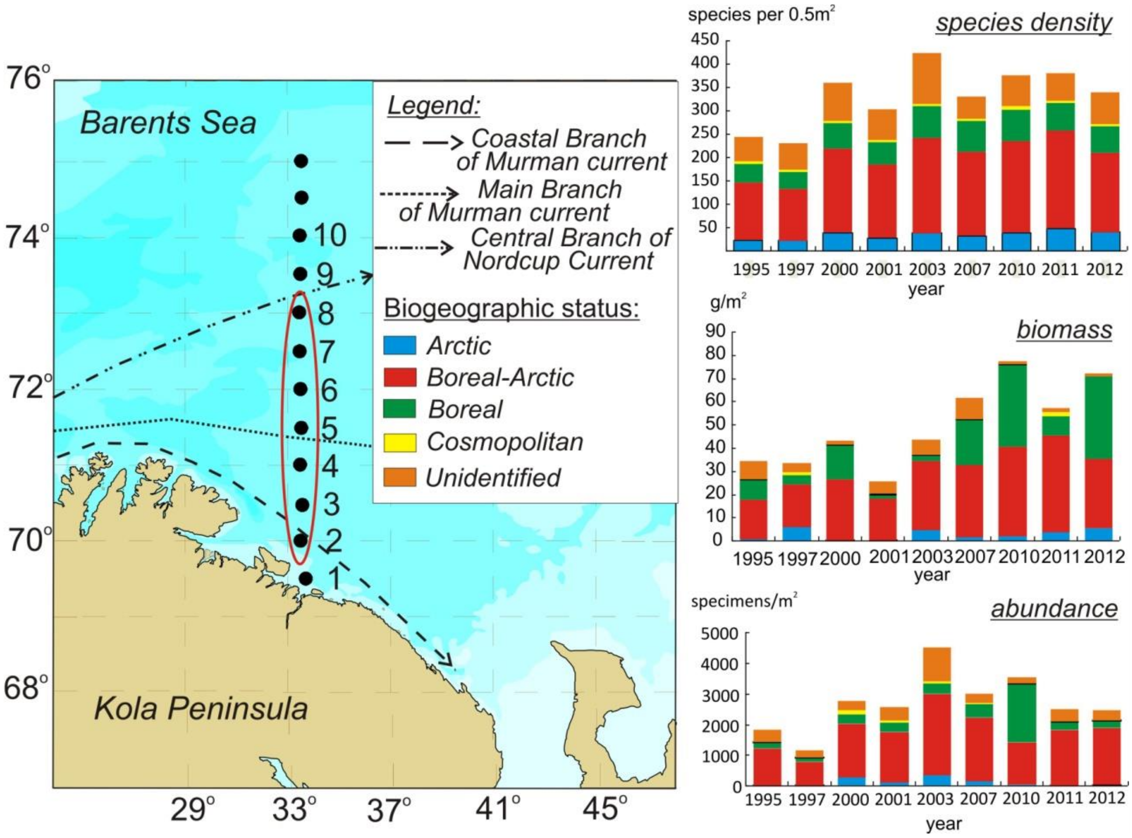


Figure 4.3.24. Biogeographic composition of zoobenthos in the Kola section (south eastern Barents Sea); the change in average species density, biomass, and abundance of zoobenthos in different years of monitoring.

During 1995-2012, the Kola section monitoring program recorded 722 species and 142 supra-species taxa, related to 241 families, 89 orders, 34 classes, and 18 phyla.

Monitoring results indicate that since 2000, the number of species (species density) has remained stable with a maximum of 15 species/0.5 m^2 interannually. The ratio of biogeographic groups of zooplankton (Arctic, Boreal-Arctic, Boreal, and Cosmopolitan) along the entire Kola section has also been quite stable since 2000. In 2007, however, an increase was indicated in the relative number of boreal species (Figure 4.3.24). This increase followed the historical maximum temperature anomaly recorded in 2006. The "maximum biodiversity indicator" (i.e. total number of species/species density) was recorded in 2003 with temperatures close to the long-term mean. Also during 2003 increases in numbers of both Boreal and Arctic species were measured together with a maximum abundance of benthic organisms along the Kola section (Figure 4.3.24). These results confirm previously published studies describing the biogeographic composition of zoobenthos biomass, abundance, and species diversity — relating this with prevailing temperature conditions (Nesis, 1960; Denisenko, 2006; Frolova et al., 2007; Matishov et al., 2011).

During the 17-year (1995-2012) monitoring period, benthic biomass peaked in 2010 due to an increase of boreal species in the southern part of the Kola section (Stations 2-5, Figure 4.3.25) and an increase of boreal-arctic species in the northern part (Station 8). This increase is believed to result from the long period of warming, and abnormally high bottom temperatures, observed between 2006 and 2012.

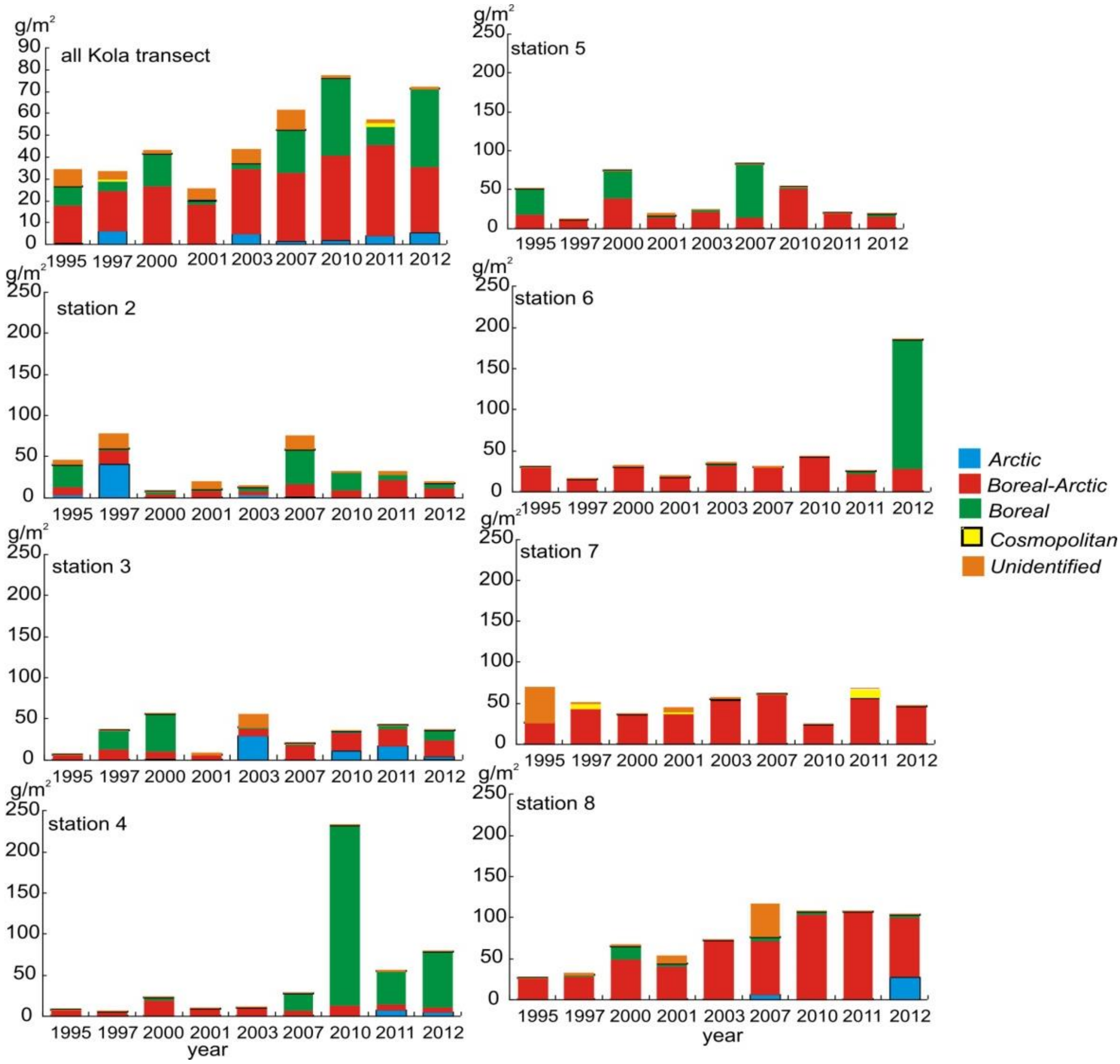


Figure 4.3.25. Benthic biomass changes at Kola transect stations during the period of investigation.

Benthic biomass increases with increasing temperatures at the Kola section due to the dominants of Boreal-Arctic and Boreal species (Frolova et al., 2007; Denisenko, 2006; Denisenko, 2007). Data also suggest that with decreasing near-bottom temperatures reductions in total benthic biomass and abundance can be expected; during longer periods of cooling, species diversity may also be reduced.

Typically, an increase in biodiversity and abundance of Arctic species is observed with cooling water temperatures; but because they represent less than 9-12% of benthic fauna in the Kola section, the contribution of the Arctic species will be minor, even with significant cooling. An overall decrease in biomass and abundance of benthic organisms was recorded in 2001 at the Kola section. This occurred approximately 4 years after a pair of cold years in the late 1990s (1997-1998). A significant increase in biomass was recorded in 2006, and again in 2010, after 4 years of unusually warm bottom temperatures. The response period for benthic biomass to changing temperature conditions (4 years) coincides with the recovery period for benthic communities after destructive impacts.

Changes in benthic community structure were observed during the period investigated in some areas of the Kola section. A dramatic increase in abundance of the boreal-subtropical bivalve mollusk (*Modiolula phaseolina*) was recorded at “Station 2” in the Kola section during a period of abnormally warm years. Previously, this species had not been observed in this area, but in recent years it has been ranked among dominant species in bottom communities in terms of both biomass and abundance. Changes also occurred in the prevalence of polychaete (*Spiochaetopterus typicus*) communities in the northern part of the Kola section (stations 6-8); this species increased from 17% of total biomass in 2000 to 65% in 2010. Together with this increased biomass of *Spiochaetopterus typicus*, an increase occurred in total biomass of the entire benthos community at these stations. These changes can be explained as natural succession in benthic communities affected by abnormal temperature change.

Both abiotic (e.g., temperature and substrate) and biotic factors influence species composition and abundance of zoobenthic communities. Predation pressure is the most important biotic factor regulating zooplankton (Timofeev, 2001). The most important benthic predators are demersal fish, primarily cod and haddock (Bohanov et al., 2013). With changing temperatures, cod follow different migration routes. In "cold" years, cod feeding migration occur mainly along the coast of the Kola Peninsula; this increases the pressure on the benthic community that is already impacted by lower temperatures. In "warm" years, cod feeding grounds are found in northern and eastern regions of the Barents Sea (Matishov et al., 2011), reducing pressure on zoobenthos in the southern region. It can therefore be assumed that a high impact on zoobenthos from predatory demersal cod correlates with low temperatures.

The red king crab is another large benthic predator that has a large impact on the benthic community near the shores of Western Murman (Stations 1 and 2, Kola section) (Annon., 2008; Pavlova, 2008). The red king crab prefers mostly large specimens of bivalves, sea urchins, sea stars, and brittle stars (Annon., 2008; Pavlova, 2008). The benthic community at Station 2 of the Kola section differs from others in having high species diversity and abundance, and generally organisms with relatively smaller body size. It can be assumed that the predatory impact from the red king crab on the zoobenthos of southern stations has been ongoing since the early 2000s. Previous studies of the red king crab’s impact on the benthos in Motovskyi Bay indicated significant changes in the structure of benthic communities. Similar changes were observed at the stations mentioned above.

4.3.5 Commercial shellfish: status of commercial stocks

S. Bakanev (PINRO), A. Dvoretsky (MMBI), V. Pavlov (PINRO), M. Pinchukov (PINRO), D. Zacharov (PINRO), and P. Zolotarev (PINRO)

Three marine invertebrate species are traditionally harvested in the Barents Sea: the red king crab, northern shrimp, and Icelandic scallops. In 2013, a commercial fishery for the non-indigenous snow crab species (*Chionoecetes opilio*) was initiated in the Barents Sea.

4.3.5.1 Red king crab (*Paralithodes camtschaticus)*

Introduced species have been identified as major agents of global change and one of the main threats to marine systems because of their direct and indirect impacts on native ecosystems. Their effect on biodiversity, habitat structure, and economically important fisheries is a major source of concern (Dvoretsky and Dvoretsky, 2010; Falk-Petersen et al., 2011). The red king crab (*Paralithodes camtschaticus*) is among the few large, higher trophic level marine organisms which have become established in a new geographic area. This species was introduced to the Barents Sea from the northern Pacific in the 1960s to establish a new commercial fishery. The first attempts to introduce the crab into the Barents Sea were undertaken in 1931–1932, but were unsuccessful due to inadequate long-distance transport facilities for live crabs at that time. Subsequent attempts were undertaken during 1960–1970 by staff at the MMBI KSC RAS (Murmansk Marine Biological Institute, Kola Science Centre, and Russian Academy of Sciences). During this period about 3,000 adult red king crabs (6–15 years old), 10,000 juveniles, and 1,600,000 larvae were released into the southern Barents Sea, mainly into Kola Bay and adjacent areas of Western Murman. Recently mature crabs, juveniles, and larvae transported from the Far East were also released in the waters of Eastern Murman (Dalnezelenetskaya Bay). These newly released red king crabs were originally caught in Peter the Great Bay (the Sea of Japan) and off the southwestern coast of Kamchatka, the Sea of Okhotsk (Kuzmin and Gudimova, 2002). Until the late 1980s, measurements of red king crab abundance did not exceed 100 thousands individuals. In the early 1990s, the population started to grow exponentially reaching 5–10 million individuals within a few years; this coincided with warming temperatures in the Barents Sea. In 2003, the estimated population size reached 20 million individuals (Figure 4.3.26). Experts believe that such a large population will inevitably lead to decreased biomass of the crabs' benthic prey organisms, which will lead to significant changes in structure and dynamics of the coastal ecosystem. Recent studies, however, do not support this opinion. Long-term studies have shown that some changes in local bottom communities — associated with the impact of the red king crab — could be detected, but negative effects on the benthic ecosystem were not detected (Britayev et al., 2010). Moreover, it is believed that introduction of the red king crab has resulted in positive economic benefits with no apparent detrimental effects on fish stocks (Dvoretsky and Dvoretsky, 2015).

During 2009-2013, PINRO conducted targeted surveys using various gear types (traps, divers, and trawls) in the Russian Economic Zone (REZ) to investigate the status of the king crab population within the 12-mile coastal zone and in the open sea (Figure 4.3.27).

Surveys, conducted within the 12-mile zone, revealed dense aggregations (over 1,000 ind./km^2) consisting of mainly females and juveniles in the entire coastal area of Western and Eastern Murman, and at the northern tip of Cape Kanin Nos (Figure 4.3.27).

Surveys conducted outside the 12-mile zone indicated that feeding aggregations of crabs (mainly commercial sized males and pre-recruits) in the open sea were limited in size and occurred at low densities, usually not exceeding 500 ind./m^2. In 2012, the area with aggregations of more than 1,000 ind./m^2 significantly increased; in 2013 similarly dense aggregations occupied most of the area surveyed, including areas of the Kanin Bank and Kanin-Kolguev Shallows adjacent to the Murman Shallows (Figure 4.3.27). Hence, survey results indicated not only an increase in the total red king crab population from 2011 to 2013, but also an eastward expansion of its dense feeding aggregations.

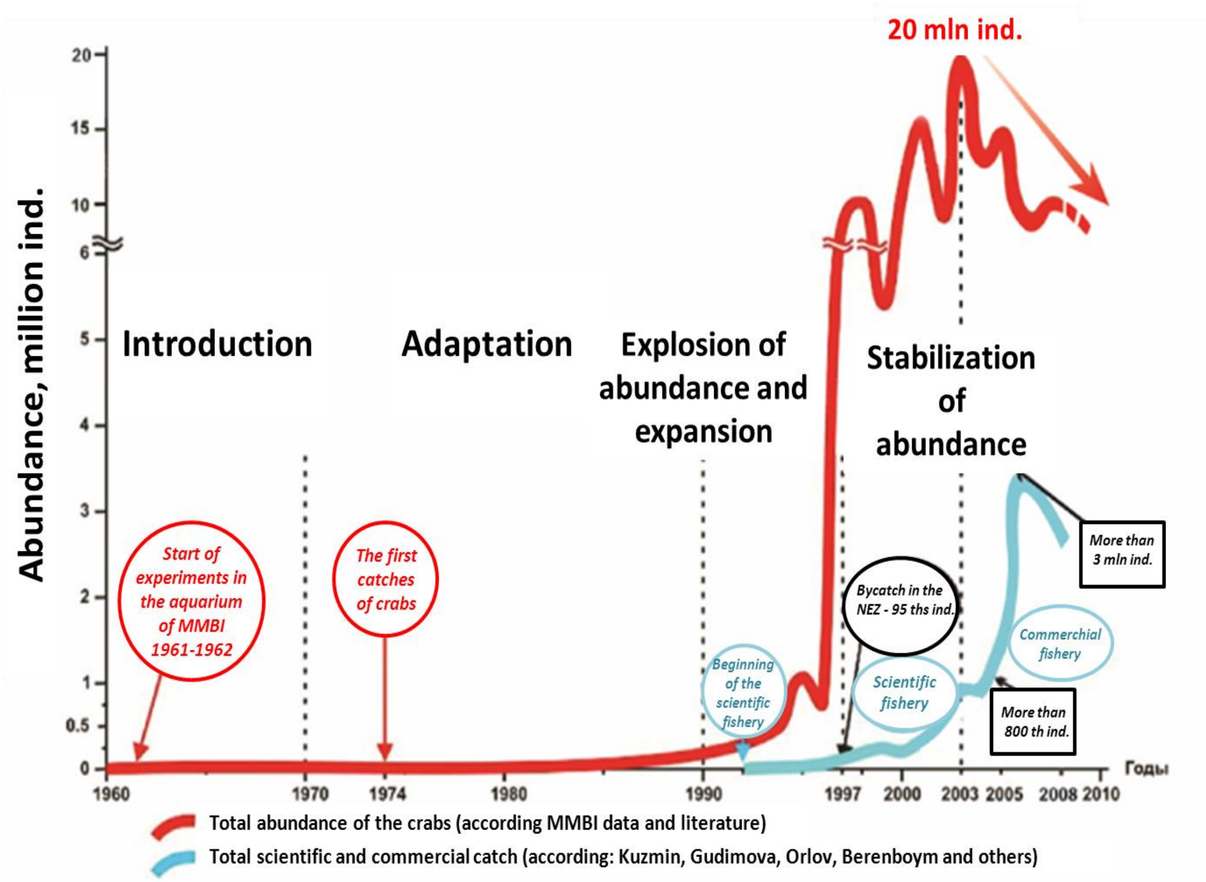


Figure 4.3.26. Population expansion of red king crab in the Barents Sea linked to the warming in the early 21st century

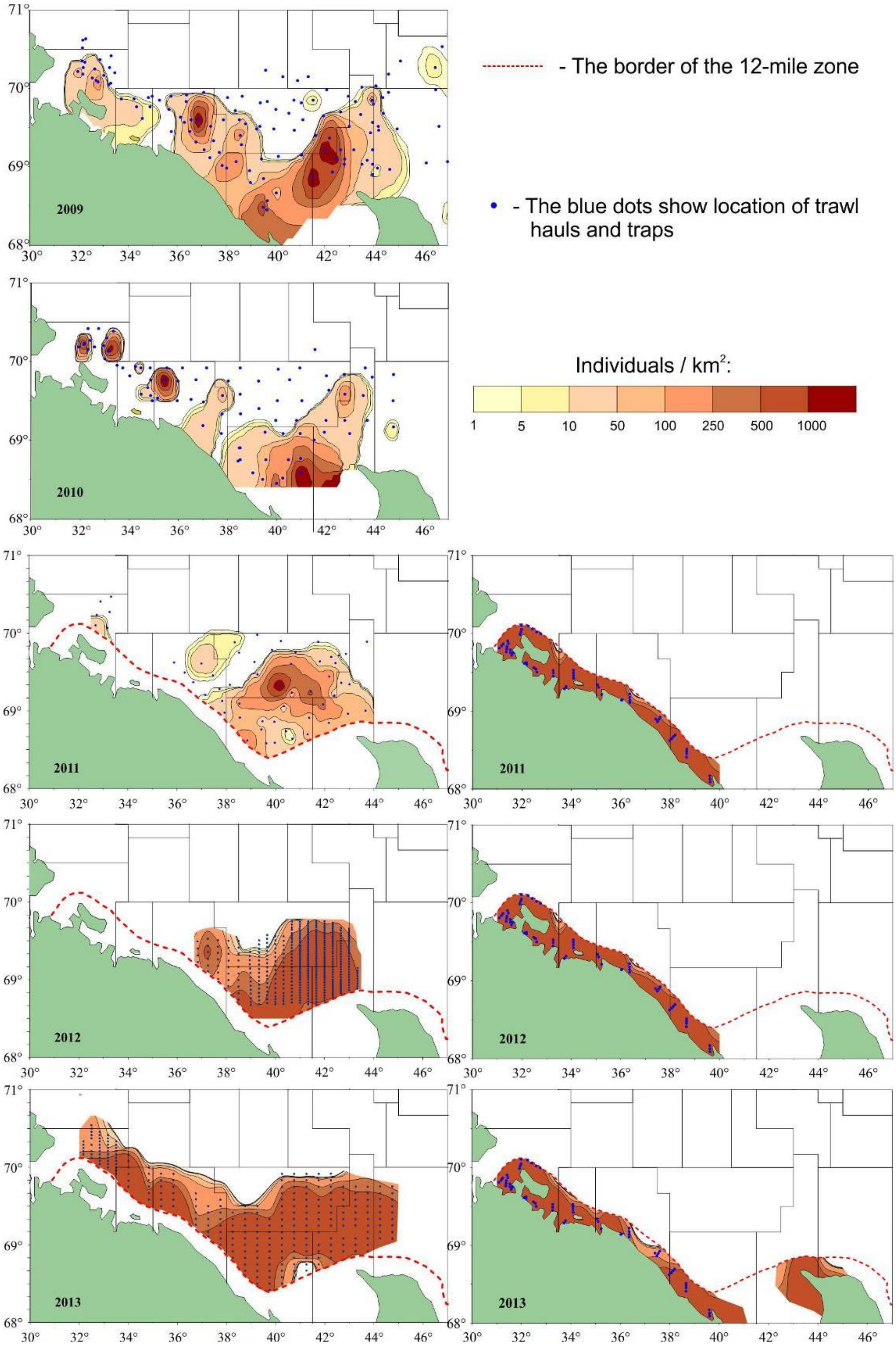


Figure 4.3.27. Distribution of total abundance of king crab in the open Barents Sea (left) and territorial waters of Russian Federation (right) in 2019–2013, ind./km^2.

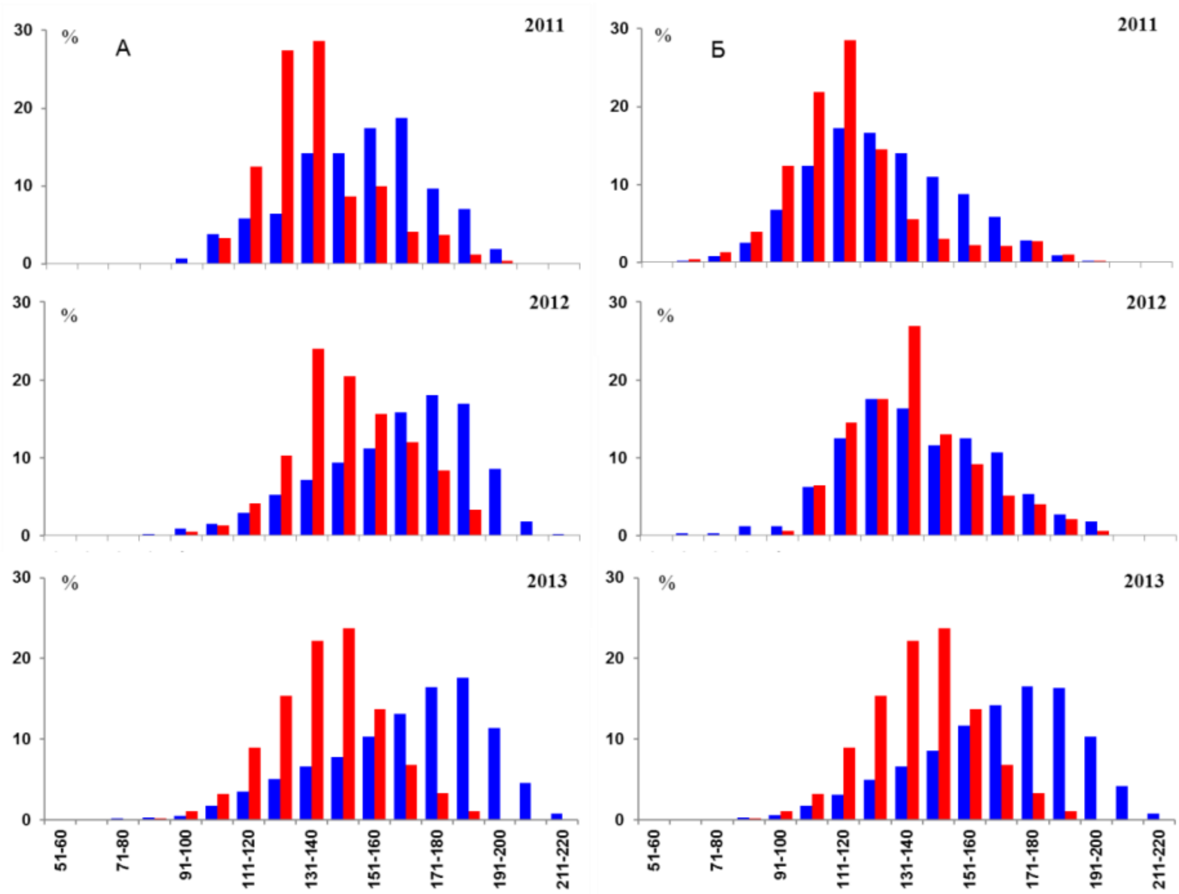
Estimated stock size indices also indicated a significant increase (during 2011-2013) in the total abundance of red king crabs in open waters of the Barents Sea, and in the number of market-sized crabs within the population (Table 4.3.2).

Table 4.3.2. Stock indices for red king crabs in the REZ of the Barents Sea (Bakanev, Pinchukov, 2014).

Year	Stock indices, thous. ind.		
	Total	Pre-recruits I	Commercial
2009	8,382	338	1,504
2010	19,198	2,434	1,583
2011	13,331	1,311	2,965
2012	*	3,426	11,875
2013	69,160	5,231	25,009

* Total stock size index is not given due to the limited area of survey coverage in 2012

Changes in population structure during the 2011–2013 surveys indicate an increase in market-sized crabs resulting from the strong 1997 year class (Figure 4.3.28).



Carapace width, mm

Figure 4.3.28. Size structure of the red king crab population in the open waters (A) and coastal waters (B) of the Barents Sea in 2011–2013. Blue bars: males; red bars: females.

Due to a ban on red king crab harvesting in the coastal area of the Kola Peninsula, crab fishing was conducted outside the 12-mile zone in the Russian EEZ. During 2011–2013, all harvesting was concentrated in the east near the Murman shallows, the northern part of the Eastern Coastal Area, and the Kanin Bank. Increased catches were registered due to increases in abundance, distribution, and density of market-sized crabs, and the eastward expansion of dense aggregations of market-sized crabs (Figure 4.3.29).

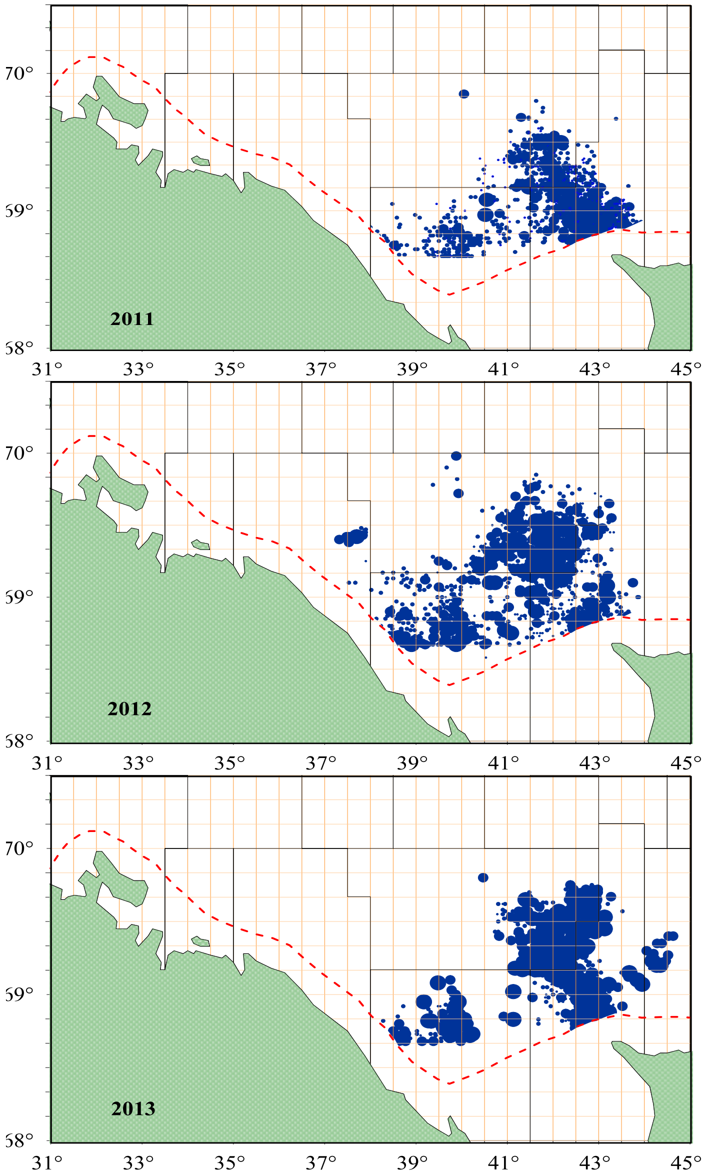


Figure 4.3.29. Red king crab fishing intensity and area in the Barents Sea in 2011–2013; circle size is proportional to catch index.

A negative trend was observed in red king crab population dynamics from 2006 to 2010 (Table 4.3.3); this was largely caused by natural dynamics related to strong year class abundance, and by excessive fishing pressure. Accordingly, total allowable catch (TAC) of red king crab during 2009 and 2010 was reduced from 10 to 4 thousand tonnes. This measure had a positive effect on the population, and the catchable component increased noticeably with recruitment of the strong 2007 year class. This made it possible to increase TAC in 2012 to 5.5 thousand tonnes, and in 2013 to 6 thousand tonnes (Table 4.3.3).

Table 4.3.3. Total allowable catch and main harvesting parameters of red king crab during 2006–2013 (Bakanev, Pinchukov, 2014).

Years	Commercial Stock index, Thous. ind.	TAC thous. Tonnes	Yearly catch, thous. ind.	Yearly catch, thous. tonnes	Standardized Catch Kg/trap*
2006	6,639	14.60	3,086	12.639	120
2007	5,747	12.72	2,729	10.934	95
2008	4,305	12.48	2,389	9.291	66
2009	1,504	10.40	1,971	6.309	57
2010	1,583	4.00	1,313	3.940	58
2011	2,965	4.00	1,246	3.702	83
2012	11,875	5.50	1,736	5.209	103
2013	25,009	6.00	1,784	5.531	163

* – Standardized catch index for American rectangular trap.

4.3.5.2 Snow crab (*Chionoecetes opilio*)

Ecosystem surveys have shown exceptionally rapid growth of the snow crab – especially in the waters adjacent to the northern island of the Novaya Zemlya archipelago – and the expansion of its range in the north-east direction (Figure 4.3.30).

During 2009-2010, average catches in this area were 100-150 individuals per standard 15-minute tow. Crabs were captured at depths ranging from 50 to 450 m; however, the largest catches were recorded from the 130-160 m range. Males and females of all ages with carapace width ranging from 10 to 140 mm, and from 13 to 81 mm, respectively, were present in the catches. But catches were mainly dominated by males with carapace width ranging from 11 to 30 mm; this accounted for approximately 80% of the total number of crabs caught.

Quantitative parameters of snow crab trawl catch in the 2011–2013 ecosystem surveys indicate a significant increase in population size during this period (Table 4.3.4).

In 2011, juvenile crabs with carapace width less than 40 mm and modal sizes of around 2-2.5 cm dominated size structure of the population (Figure 4.3.31). In 2012, natural increases were observed in both modal group size (to 3.5cm) and average weight of individual crabs in catches. In 2013, catch size structure indicated emergence of another strong year class (likely to have occurring during 2011-2012) with modal sizes of 0.5–1.5cm within the population. By 2013, however, abundance of this year class had not yet compensated for natural declines in abundance of previous year classes. Hence, 2013 registered a slight decline in relative population abundance (average size and total number of individuals per catch); while quantitative indices and average weight of individuals were increasing (Table 4.3.4; Figure. 4.3.31).

Table 4.3.4. Indices from quantitative assessment of snow crab population abundance, data from IRM-PINRO ecosystem surveys, 2011–2013.

Parameter	Year:		
	2011	2012	2013
Number of effective trawl hauls with snow crabs	79	121	131
Maximum catch, kg/trawling	19.6	137.9	189.3
Maximum catch, ind/trawling	1926	5407	2251
Average catch, kg/trawling	1.9	8.2	9.2
Average catch, ind/trawling	79	232	158
Total catch per survey, kg	152	1001	1209
Total catch per survey, ind.	6202	28100	20659
Average weight, g	24	36	59

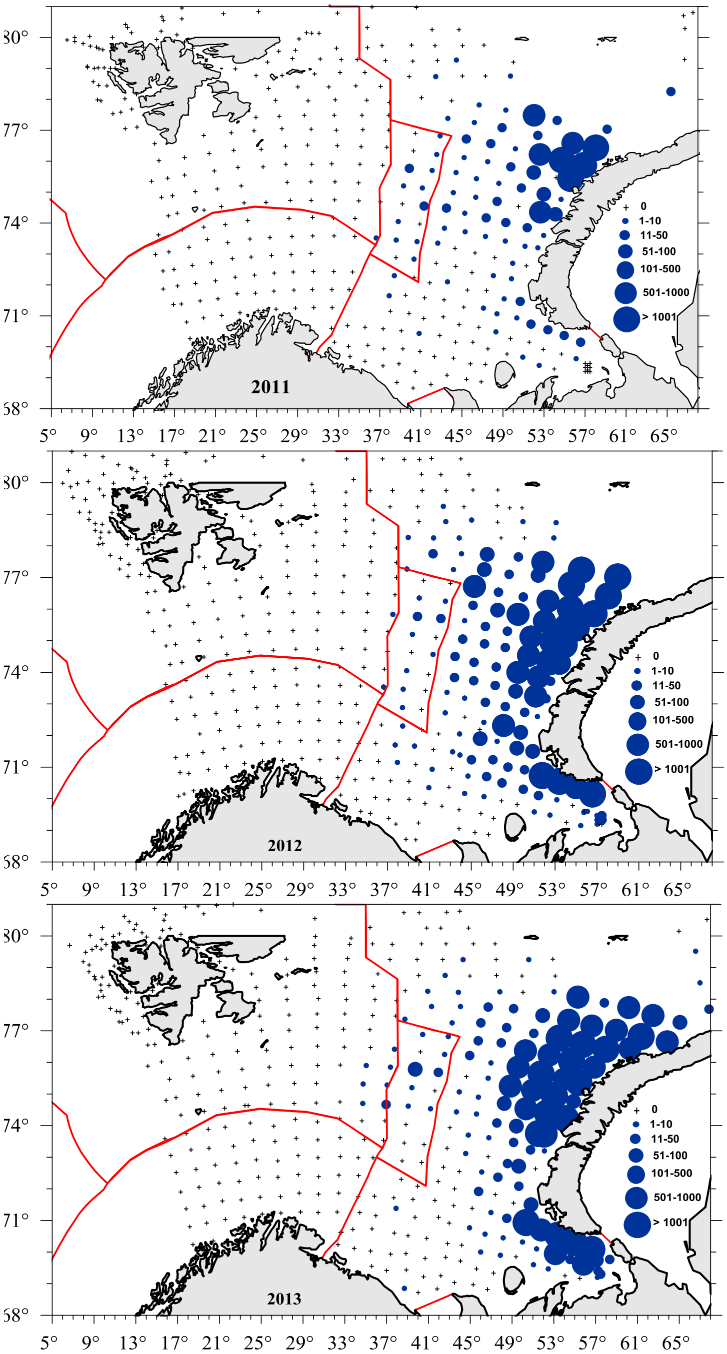


Figure 4.3.30. Distribution of snow crabs in the Barents Sea, data from IMR-PINRO ecosystem surveys during 2011–2013, ind./15 min. trawl haul.

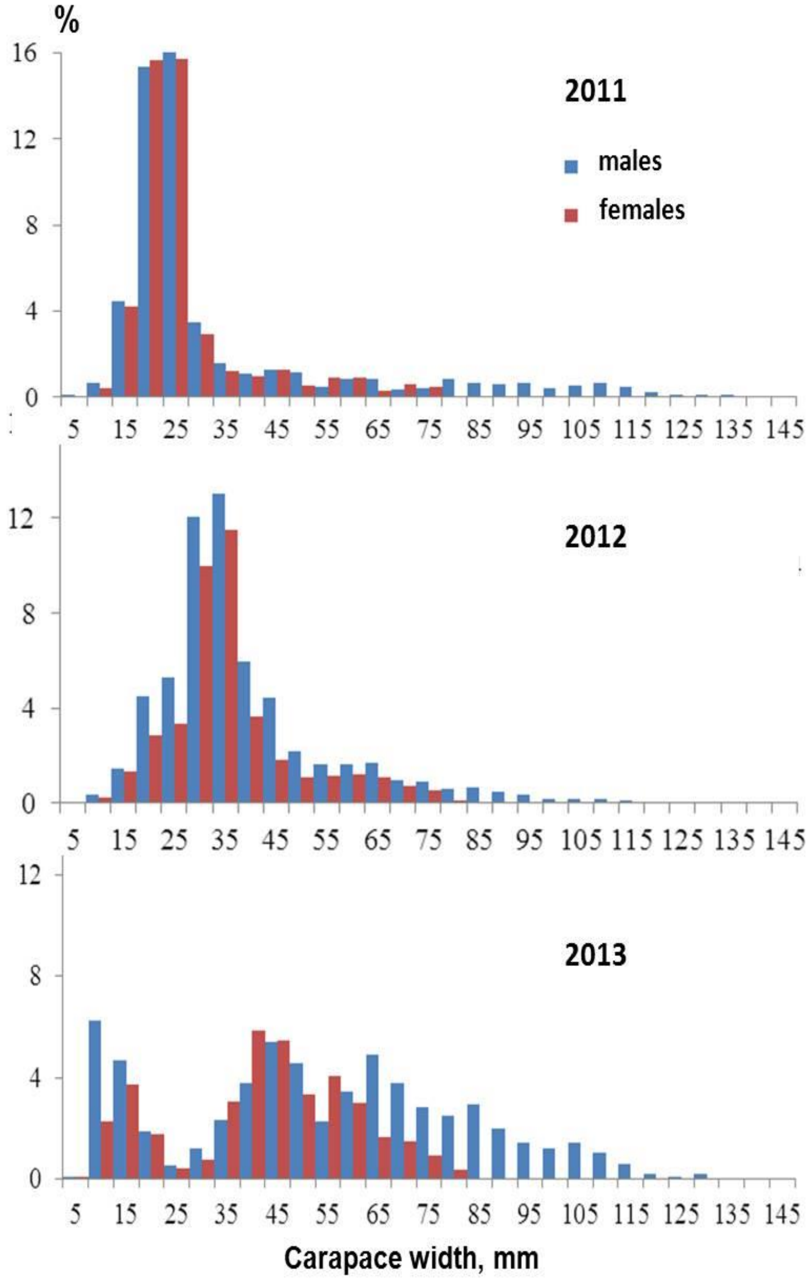


Figure 4.3.31 Size composition of the snow crab population in the Barents Sea, data from ecosystem surveys conducted during August–October 2011-2013 (Bakanev, Pavlov, 2014).

Ecosystem survey results indicate that the area of snow crab distribution in the Barents Sea is at least 530 thousand km^2. The densest aggregations currently occur in Novaya Zemlya waters near Southern Novaya Zemlya Trough and Novaya Zemlya Bank (Figure 4.3.30). The presence of a significant number of pregnant females and a high percentage of juveniles in the population composition suggests high efficiency of reproduction. It is evident that snow crab population in the Barents Sea is actively and successfully adapting to its new environment.

This population growth is mainly due to increased snow crab density in Novaya Zemlya waters and eastward expansion into the Kara Sea; although the area of eastward expansion is less prominent. Therefore, until 2013 the majority of the Barents Sea snow crab stock was located in the Exclusive Economic Zone of the Russian Federation (RF EEZ). Intensive growth of population abundance and dynamics of strong-year classes suggest an efficient snow crab fishery in the Barents Sea in the coming years.

In 2013, a stock assessment for snow crabs was conducted in commercial aggregations of high-density. The potential area of commercial crab fishery in the Russian part of the Barents Sea (with the catch of commercial males per trap of more than 10 ind. and 5kg) amounted to around 51 thousand km^2. Commercial biomass index for this water area was estimated to 34 thousand tonnes. The assessed value did not take into account the catchability coefficient and can be seen as the minimum value of absolute commercial biomass.

Although most of the snow stock is concentrated in the Russian part of the Barents Sea, fisheries for this species have proven effective even outside this area. Commercial fishing snow crabs started in 2013 in International Waters of the Barents Sea. Figure 4.3.32 shows the area of the Russian snow crab fishery in the Barents Sea during December 2013.

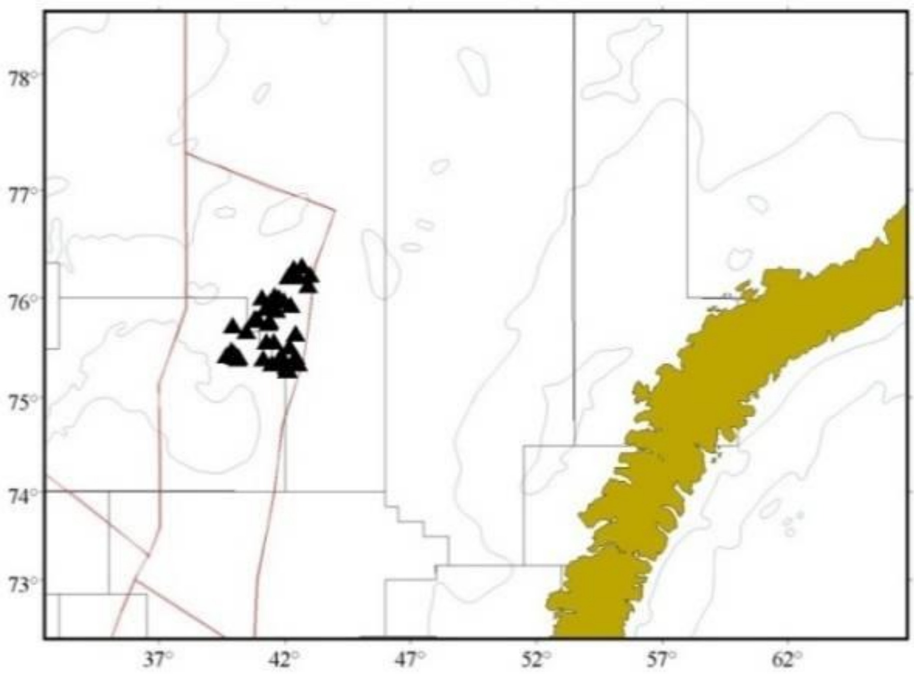


Figure 4.3.32. Area of Russian snow crab fishery in the Barents Sea in December 2013.

4.3.5.3 Icelandic scallop (*Chlamys islandica*)

Since 1990, the Russian fishery for Icelandic scallop has been conducted near Svatoy Nos in the Barents Sea, and on scallop banks in the White Sea Funnel (Figure 4.3.33). Due to harsh fishing conditions in the Funnel area — related to strong currents and, stiff bottom substrate — most scallops were traditionally fished in the Svyatoy Nos colony area. A sharp decline in condition of the Svyatoy Nos scallop colony — following multi-year fishing activities — lead to termination of the fishery in this area during 2009 and 2010. Kovda, the only Russian specialized scallop vessel in the Barents Sea at that point, switched entirely in 2010 to fishing for scallops in the White Sea Funnel. During the three years that followed, fishing on the

Svyatoy Nos scallop colony resumed, but the catches were lower than in the White Sea Funnel (Figure 4.3.34).

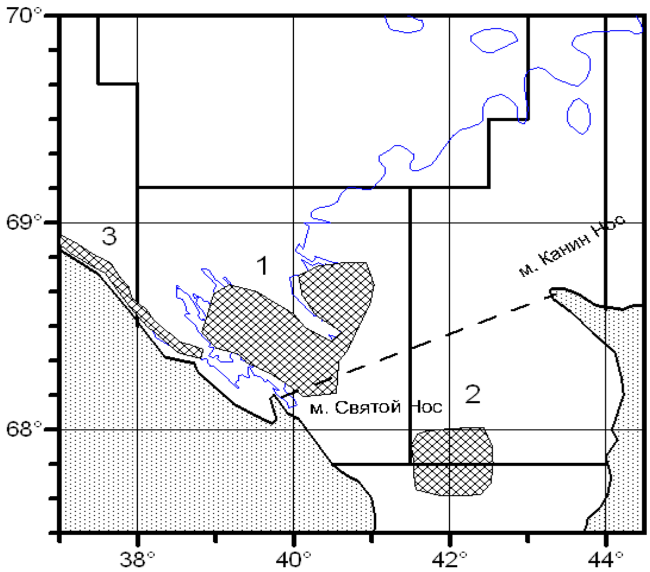


Figure 4.3.33. Areas of scallop commercial stock surveys in the Barents and the White Seas. 1 – Svyatoy Nos settlement; 2 – aggregation in the White Sea Funnel; 3 – Coastal aggregation; dashed line – border between the Barents and the White seas.

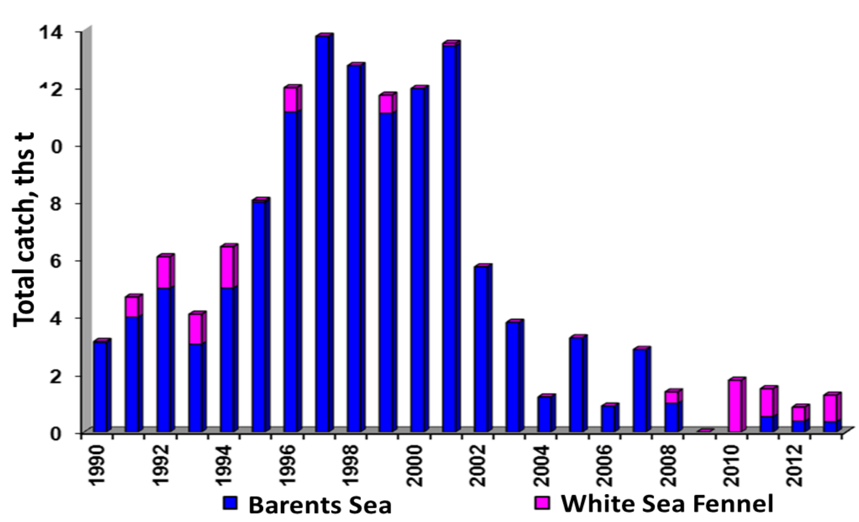


Figure 4.3.34. Annual catch of the scallop in the Barents Sea (at Svyatoy Nos settlement) and in the White Sea Funnel in 1990–2013 (Zolotarev, 2014).

During 2011-2013, 533, 440, and 362 metric tons of scallops were landed, respectively, at the Svyatoy Nos colony; while landings from the Barents Sea Funnel, were 973, 490, and 921 tonnes, respectively. During those years, average catch efficiency was higher for the White Sea Funnel fishery (15–22 t/vessel-day of fishing) than for the Svyatoy Nos colony fishery (11–13 t/vessel-day of fishing).

Starting in the 1990s, PINRO conducted cooperative trawl surveys of Icelandic scallop stocks in the White and Barents seas with scallop harvesting vessels Kovda and Skoloper fishing alongside each other. These surveys were limited to the two main commercial colonies near Svyatoy Nos in the Barents Sea and in the White Sea Funnel. Data to analyze scallop colony condition were taken from catches by commercial drags. Termination of the fishery in 2009 resulted in radical changes in scallop survey sampling procedure. Starting in 2009, PINRO conducted surveys on RV “Professor Boyko” using the traditional hydro-biological Sigsbee trawl as fishing gear. These changes contributed to a significant expansion of the survey area, and enabled assessment of scallop colony condition not only in traditional fishing areas, but also in areas not currently harvested: on the Goose Bank; the northern slope of Kanin-Kolguev shallows; and North-Kanin and Kanin banks. None of these sites had been noted earlier to have dense scallop clusters of commercial interest. Intensive fishing at the end of the last century, likely has resulted in irreversible changes in the structure of benthic communities and scallop populations.

According to 2010 results, the total area of scallop beds within Svyatonossky Gulf and coastal settlements was estimated at 1.9 thousand sq. km. Biomass of commercial-sized scallops within these settlements ranged from 1 to 800 g/m^2, but did not exceed 300 g/m^2 in most of the study area. The densest concentrations of scallop biomass, with more than 500 g/m^2, were noted in the south-eastern part of the Svyatonossky settlement near Nokuev Islands and in the Seven Islands archipelago (Figure 4.3.35). Based on the settlements surveyed, the total scallop stock in the Barents Sea amounted to about 283 thousand tonnes, with a commercial stock of 230.7 thousand tonnes, which is 1.2 times more than estimated in 2009.

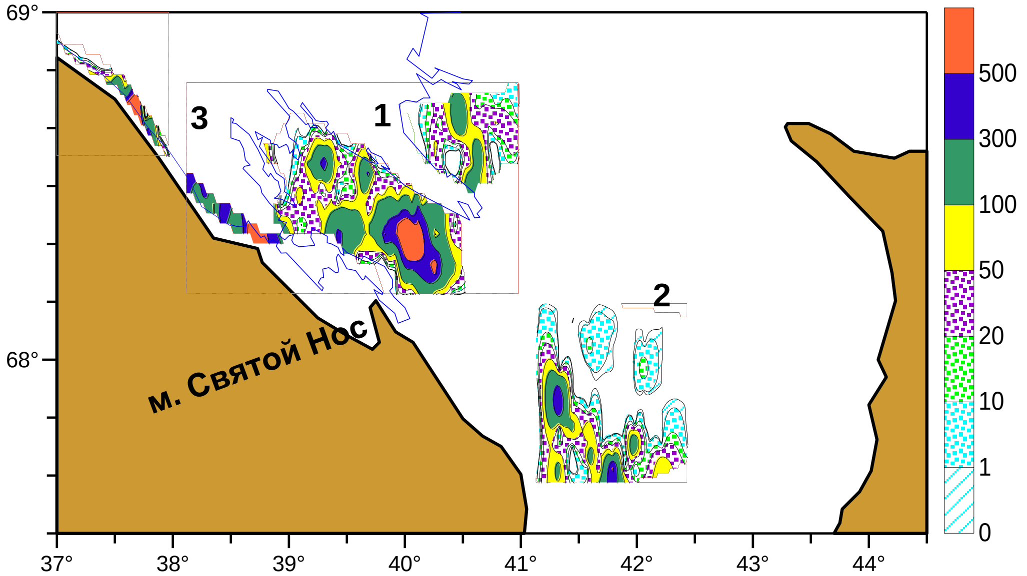


Figure 4.3.35. Distribution of scallop biomass in clusters in the Barents and White Seas in 2010. 1 – Svyatonossky settlement; 2 – settlement in the funnel of the White Sea; 3 – The coastal settlement (Bakanev, Zolotarev, 2011).

Scallop biomass was lower in the Funnel of the White Sea; highest values were observed in the southern and western parts, and did not exceed 500 g/m^2. The commercial stock in the White Sea Funnel was estimated at 140 thousand tonnes, which was slightly higher than in 2009.

Using survey data, commercial stocks of Icelandic scallop were assessed at three main aggregations in the White and the Barents seas. Derived estimates indicate that the commercial scallop stock remains at the lowest point in 25 years, while exploited colonies in the southern Barents Sea can be characterized as low but stable.

During 2011–2013, observations of epidemic outbreaks continued in the main scallop colonies. Evidence of large-scale fungal-bacterial infection among scallops was first noticed at the Svyatoy Nos colony in 2003; it became epizootic in the following years. High infection contamination leads to atrophy of soft body tissues, reduced growth rates (up to a complete stop), and significantly decreases breeding success due to gonad lesions.

During 2012–2013, a decrease in the rate of infection among scallops was observed in the Svyatoy Nos colony, although the total number of infected individuals remained high — up to 20% in some places. A similar situation was observed in the Coastal colony neat Eastern Murman shore. In White Sea Funnel, the number of infected scallops did not exceed 5%, which corresponds to the natural background.

Available data indicate that the epidemiological situation in Barents Sea scallop colonies can improve if fishing activity at the Svyatoy Nos colony is conducted at a low level. However, transfer of fishing effort to the White Sea Funnel may degrade ecological conditions in this area and result in a similar outbreak.

4.3.5.4 Northern shrimp (*Pandalus borealis*)

PINRO conducted specialized trawl surveys to assess the stock level of northern shrimp in the Barents Sea Svalbard area from 1982 to 2003. Since 2004, the stock has been assessed using the joined Russian-Norwegian ecosystem survey. During this 1982-2013 survey period, shrimp biomass has peaked at approximately 7–8 year intervals which were observed in 1983–84, 1991–92, 1998, 2006, and 2010 (Figure 4.3.36).

Ecosystem surveys results from 2011, 2012, and 2013 indicate that patterns of shrimp abundance/biomass in the Barents Sea have not varied dramatically (Figure 4.3.37). As in previous years, shrimp was distributed in 2013 extended practically over the entire Sea (excluding shallow areas in the Pechora Sea, the Persey Bank, off Bear Island, and Hopen Bank). Major shrimp populations are located in northern coastal waters of Svalbard and central north-eastern Barents Sea.

During 2011–2013, indices of northern shrimp stock abundance were estimated by area using ecosystem survey data. Estimated annual values were 377, 424, and 386 thousand tonnes, respectively, and were higher than the long-term average (Figure 4.3.36). This suggests that the Barents Sea population of *Pandalus borealis* remains in a stable condition.

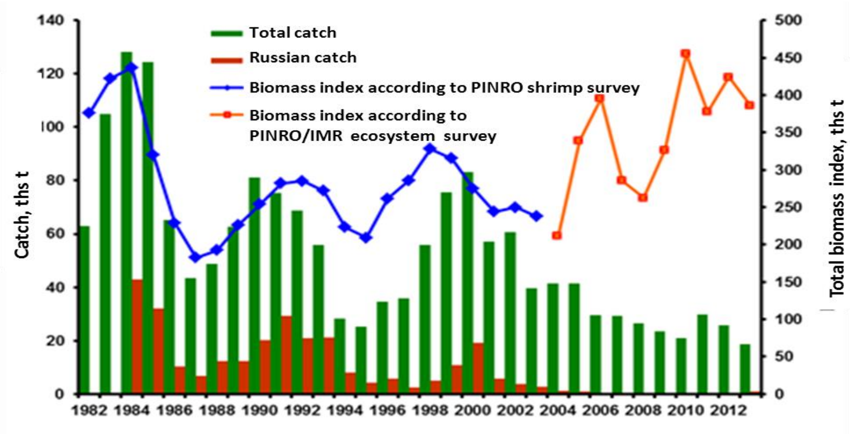


Figure 4.3.36. Biomass index and catch of northern shrimp in the Barents Sea and near Svalbard in 1982–2013 (Zacharov, 2014).

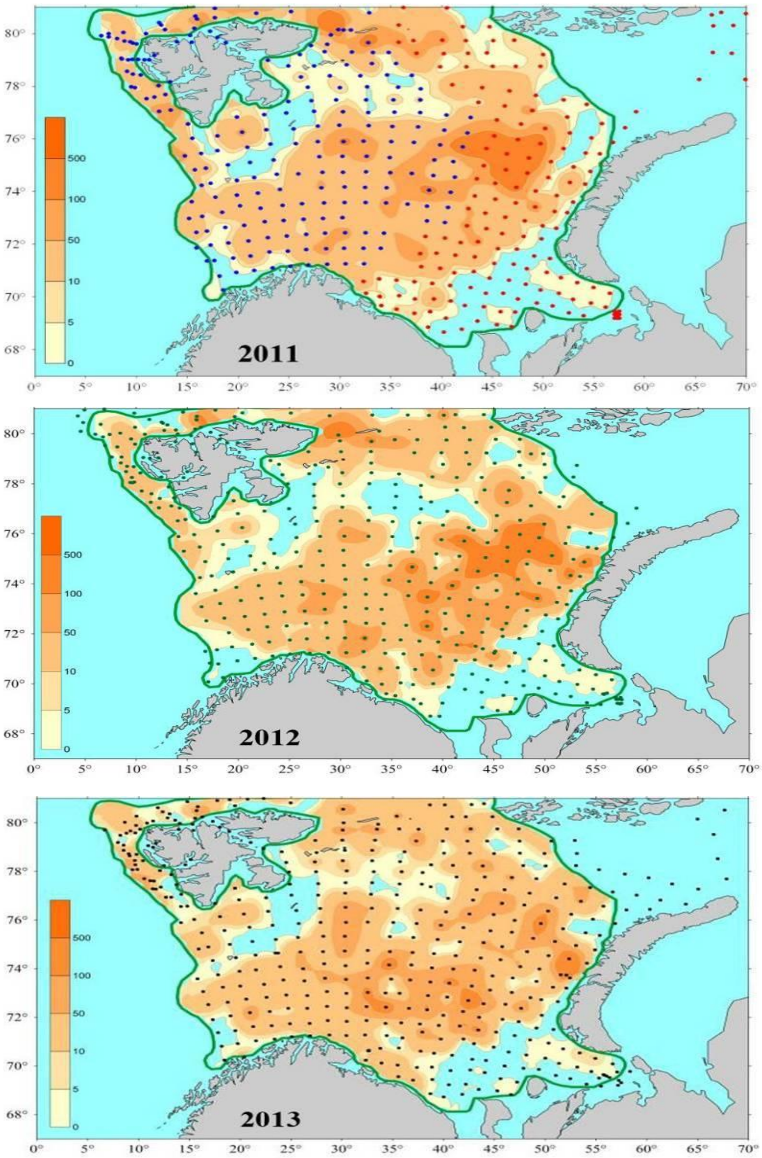


Figure 4.3.37. Distribution of northern shrimp in the Barents Sea and near Svalbard in August–September 2011–2013, kg/hour of trawling.

Commercial fisheries for northern shrimp in the Barents Sea and waters near Svalbard have been conducted regularly since 1950s; Russia joined in 1976. Although the stock is believed to be fished at a sustainable level, total catch decreased steadily after 2001, and has stabilized at around 20–30 thousand tonnes/year since 2006. Estimated catch of northern shrimp in the Barents Sea and waters off Svalbard was 30 thousand tonnes in 2011, 26 thousand tonnes in 2012, and 19 thousand tonnes in 2013.

For economic reasons, catch levels for northern shrimp in the Russian zone also decreased annually after 2000, and had dropped to 1 thousand tonnes by 2005. Catch levels have not increased in subsequent years, and had practically stopped during 2009–2012. In 2013, one Russian vessel resumed shrimp fishing in the Barents Sea, and harvested approximately 1 ton in the Novaya Zemlya shallows.

No international catch quotas are enforced for northern shrimp fisheries in the Barents Sea. Fishery regulations in the Sea and near Svalbard coast require using trawls with mesh size of at least 35mm, and use of selective grids (with 19mm spacing between bars) is compulsory. In addition, bycatch should not exceed 800 ind. cod and/or haddock, 1000 ind. red fish, and 300 ind. black halibut per 1 ton of shrimp.

4.3.6 Fish

B. Bogstad (IMR), A.V. Dolgov (PINRO), H. Gjøsæter (IMR), E.H. Hallfredsson (IMR), E. Johannesen (IMR), Y.A. Kovalev (PINRO), S. Mehl (IMR), D.V. Prozorkevitch (PINRO), A.A. Russkikh (PINRO), and O.V. Smirnov (PINRO)

4.3.6.1 Cod (*Gadus morhua*)

Based on the most recent estimates of spawning stock biomass (SSB), ICES classifies the cod stock as having full reproductive capacity and being harvested sustainably (Figure 4.3.38). The SSB has been above B_{pa} since 2002 and is now at a record high level, while the total stock biomass is at a level not seen since the early 1950s. Currently the stock is dominated by large individuals from the very abundant 2004-2006 year classes; these year classes largely support the current fishery (ICES AFWG, 2014).

Cod is the most important predatory fish species in the Barents Sea. It feeds on a wide variety of prey, including larger zooplankton, most available fish species, shrimp, and even juvenile cod. Capelin is a preferred prey for cod. Major prey items during 2013 included capelin, polar cod, juvenile cod, shrimp, Euphausiids (krill), amphipods, and haddock. The estimated 6 million tonnes of prey consumed by cod in 2013 was a decrease from the amount consumed in 2012.

Spatial distribution of the cod stock is expanding northward and eastward (Figure 4.3.39. This is due to high temperatures observed in recent years as well as high stock abundance. Additionally, the age/size structure has broadened to include more big fish which are likely to undertake longer northward migrations. It is important that the spatial coverage of research surveys be increased accordingly.

The 2014 TAC was set at 993,000 tonnes, in accordance with the harvest control rule. This is similar to the 2013 TAC that was set at 1 million tonnes (ICES AFWG, 2014).

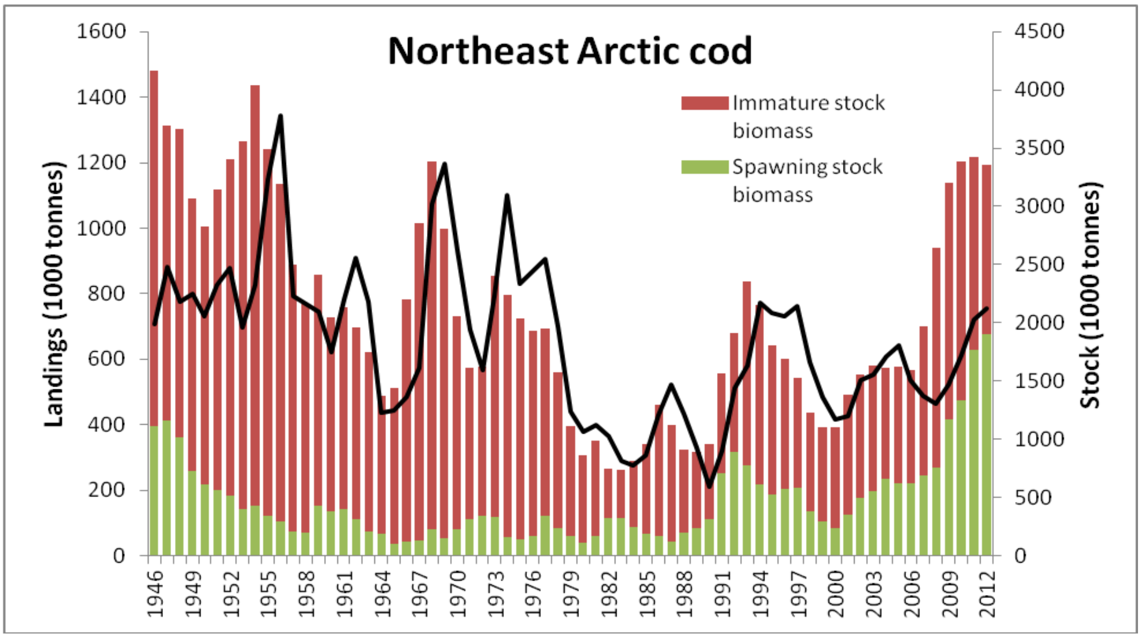


Figure 4.3.38. Northeast Arctic cod, development of spawning stock biomass (green bars), immature stock biomass (age 3 and older, red bars), and landings (black curve).

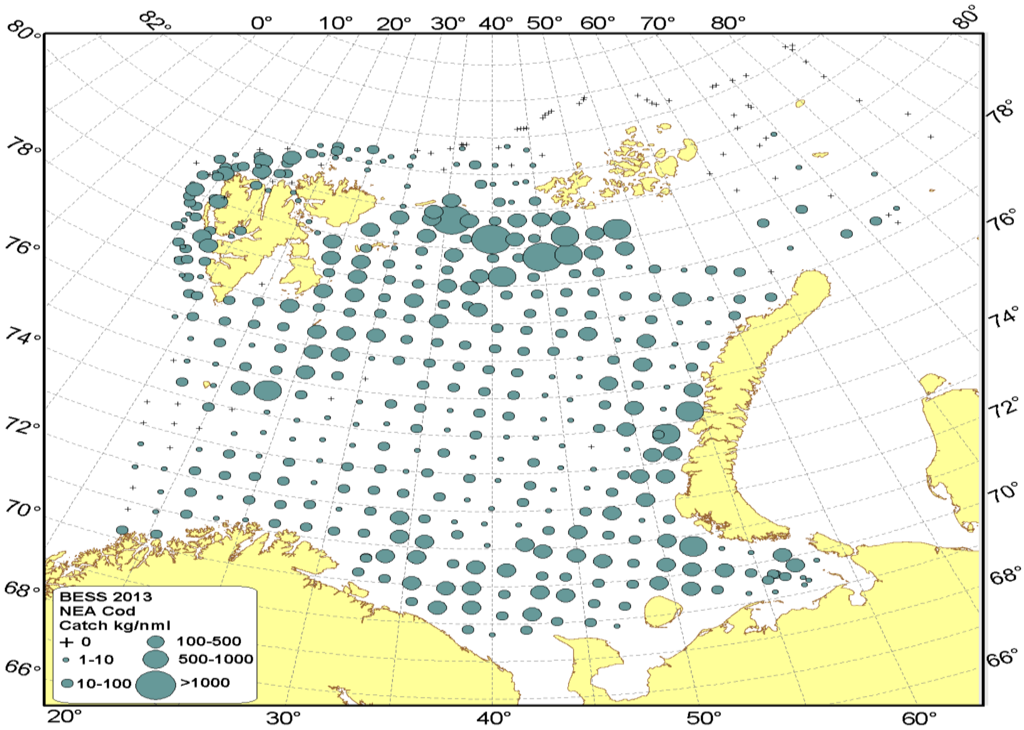


Figure 4.3.39. Distribution of Northeast Arctic cod, August-October 2013.

4.3.6.2 Haddock (*Melanogrammus aeglefinus*)

Based on the most recent estimates of SSB (Figure 4.3.40), ICES classifies the stock as having full reproductive capacity, but also in danger of being harvested unsustainably. Fishing mortality has fluctuated around F_{MSY} (0.35) during the last 10 years, but has increased considerably since 2010 and is now above F_{pa}. Very strong year classes (2004-2006) recruited to the fishable stock in 2008-2010; thus, the stock in 2010-2011 reached the highest level observed in the time series that goes back to 1950. The 2007 and later year classes are estimated to be of average size, and the stock is now decreasing. The 2014 TAC was set at 178,500 tonnes; according to the harvest control rule, it should have been set at 150,000 tonnes (a 25% reduction from 2013) (ICES AFWG, 2014).

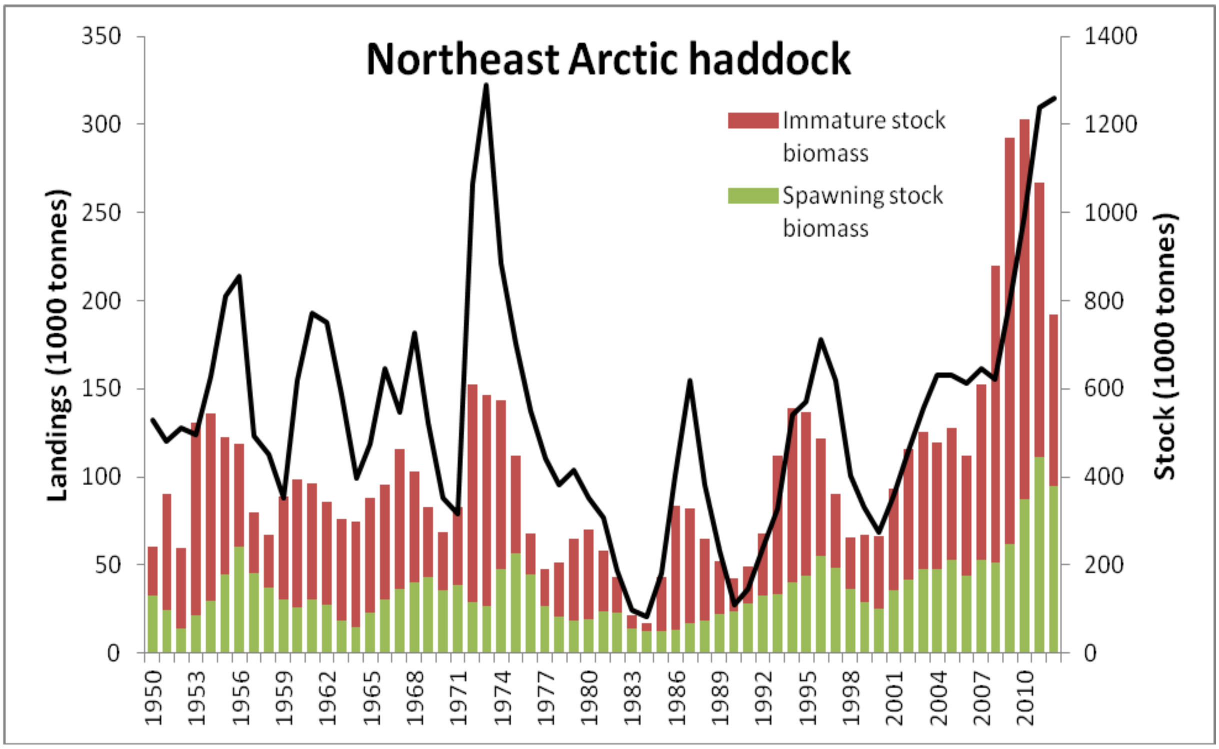


Figure 4.3.40. Northeast Arctic haddock, development of spawning stock biomass (green bars), immature stock biomass (age 3 and older, red bars) and landings (black curve).

During summer and autumn, the Barents Sea haddock stock is widely distributed in shallow waters to the north along the Svalbard/Spitsbergen Archipelago and to the east along the Murman Coast (Figure 4.3.41). At this same time, a significant part of the stock is located in the central part of the Sea (ICES AFWG, 2014).

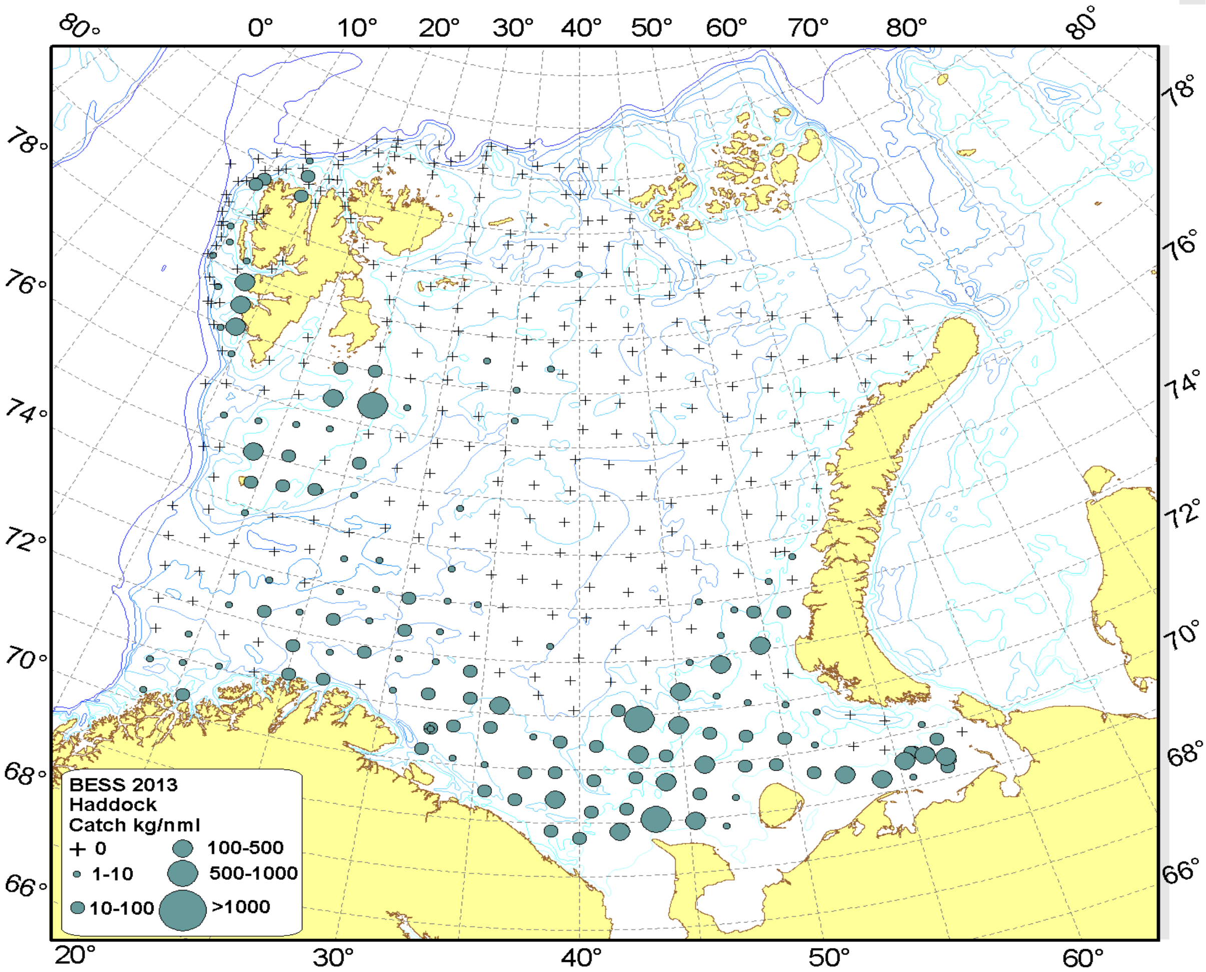


Figure 4.3.41. Distribution of Northeast Arctic haddock, August-October 2013.

4.3.6.3 Redfish (*Sebastes mentella* and *Sebastes norvegicus*)

Deep-Sea Redfish *(Sebastes mentella)*

For more than a decade, recruitment failure has been observed in Barents Sea redfish stocks (Figure 4.3.42); but signs of improvement have been observed recently. With this understanding, it is important that juvenile age groups are given the strongest protection from being caught as bycatch in any fishery, e.g., shrimp fisheries in the Barents Sea and Svalbard area where significant numbers of young redfish often occur (Figure 4.3.43). This will ensure that the recruiting year classes can contribute as much as possible to stock rebuilding (ICES AFWG, 2014).

It is likely that only year classes prior to 1995 will contribute significantly to the spawning stock in the coming years, because subsequent year classes (1996-2003) were extremely poor. Several years with management measures to ensure protection and growth of year-classes subsequent to 2003 may have caused the higher abundance and biomass recently observed along the continental slope and in pelagic waters of the Norwegian Sea. These year classes need to be protected as they offer an opportunity to increase future spawning stock size.
Since the 1990s, the fishery for deep-sea redfish (*S. Mentella*) in the Barents Sea has been restricted to by-catches in demersal fisheries. A new directed pelagic fishery for this species

in international waters of the Norwegian Sea has developed since 2004. This fishery increased to record levels in 2006 with a total catch of 33,000 tonnes, the highest level since 1991. Since then this fishery has decreased, and the total landings of *S. mentella* in Subareas I and II during 2012-2013 (demersal and pelagic catches) were around 10,000 tonnes. For many years no directed fishery has been advised for this stock. ICES decided to give advice on catch levels in 2013, after a new assessment model was accepted in 2012. The advice given for 2014 was 24,000 tonnes (ICES AFWG, 2014).

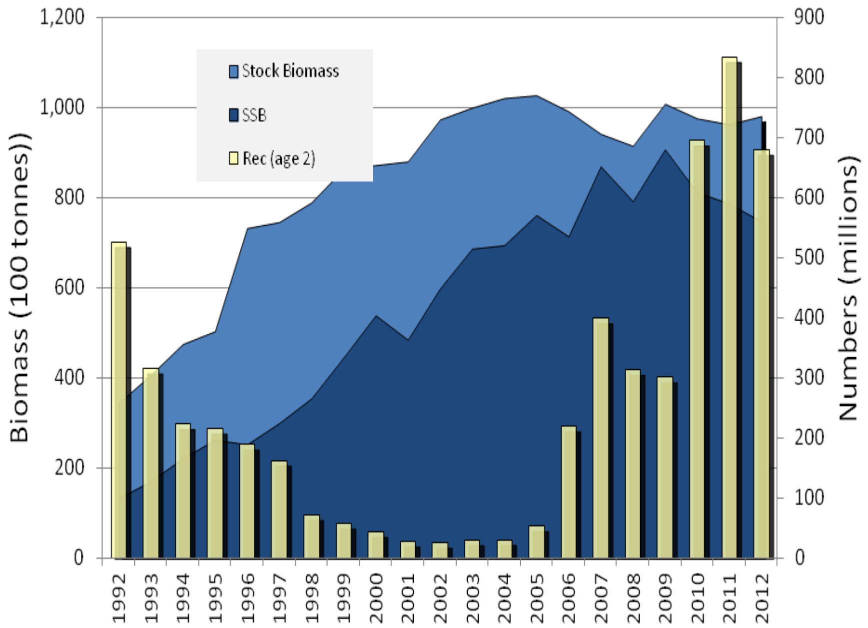


Figure 4.3.42. Results from the statistical catch-at-age model showing the development of total biomass ('000s), spawning stock biomass and recruitment at age 2 for the period 1992-2012, for *S. mentella* in subareas I and II.

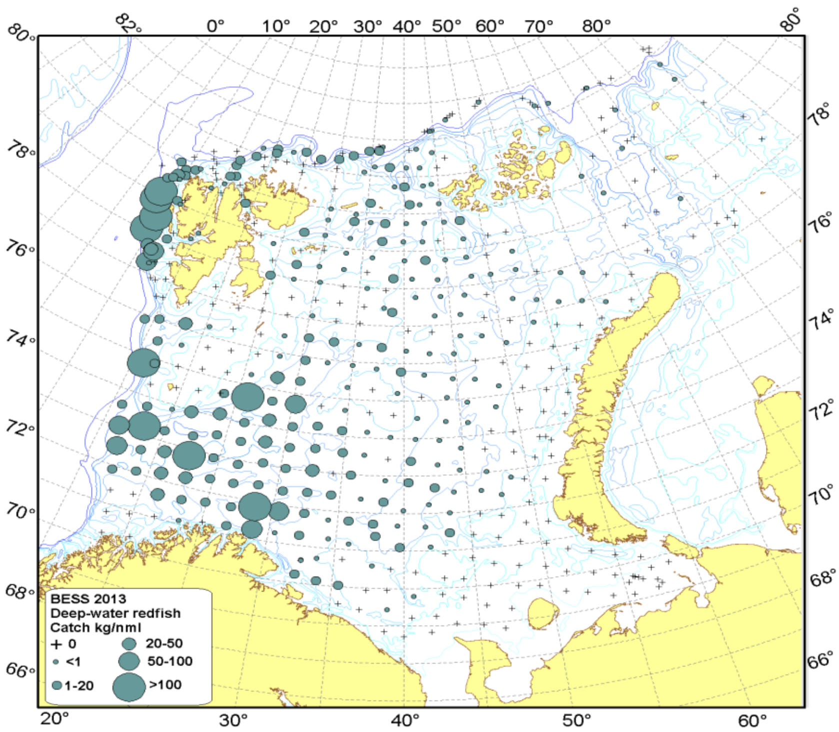


Figure 4.3.43. Distribution of deep-sear redfish in August-October 2013.

Golden Redfish *(Sebastes norvegicus)*

In the absence of defined reference points, the status of the stock cannot be fully evaluated. Year classes during the last decade have been very weak, and biomass of the mature component of the stock is less than 20,000 tonnes (Figure 4.3.44). The ICES assessment shows a substantial reduction in abundance, and indicates that presently the stock level is historically low and in very poor condition. Given the slow growth and low productivity of this species, this situation is not expected to improve within the near future (ICES AFWG, 2014).

More stringent protective measures should be implemented, such as no directed fishing and extension of the limited fishing moratorium that was implemented for this stock, as well as a further improvement of trawl bycatch regulations. It is also of vital importance that the juvenile age groups are given the strongest protection from being caught as bycatch in any fishery, e.g. the shrimp fisheries in the coastal areas as well as in the Barents Sea and Svalbard area and pelagic trawl fisheries for herring and blue whiting in the Norwegian Sea. This will ensure that recruiting year classes can contribute as much as possible to slowing stock decline. Golden redfish is currently also being caught in a directed fisheries for demersal species. Better statistics on this bycatch, and regulations to prevent this from continuing, are needed. The catches were around 7,000 tonnes in 2004-2010, but declined slightly to below 6,000 tonnes in 2011-2012. These catch levels seem to contribute to a continued decline in this stock (ICES AFWG, 2014).

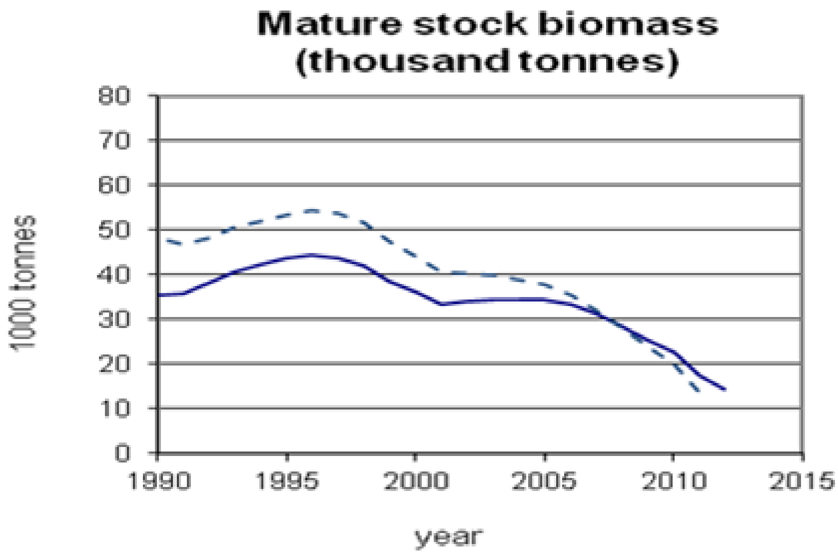


Figure 4.3.44. *Sebastes norvegicus*. Mature stock biomass (in thousand tonnes). Bold line – 2013 assessment, dotted line – 2012 assessment.

4.3.6.4 Greenland halibut (*Reinhardtius hippoglossoides*)

Greenland halibut is widely distributed in the Barents Sea. Catches are highest along the continental slope where the main spawning grounds are located (Figure 4.3.45). The northern and north-eastern part of the Sea is regarded as a nursery area for the stock (Figure 4.3.46). This species is also relatively abundant in many of the deep channels running between shallow fishing banks of the Barents Sea (ICES AFWG, 2014).

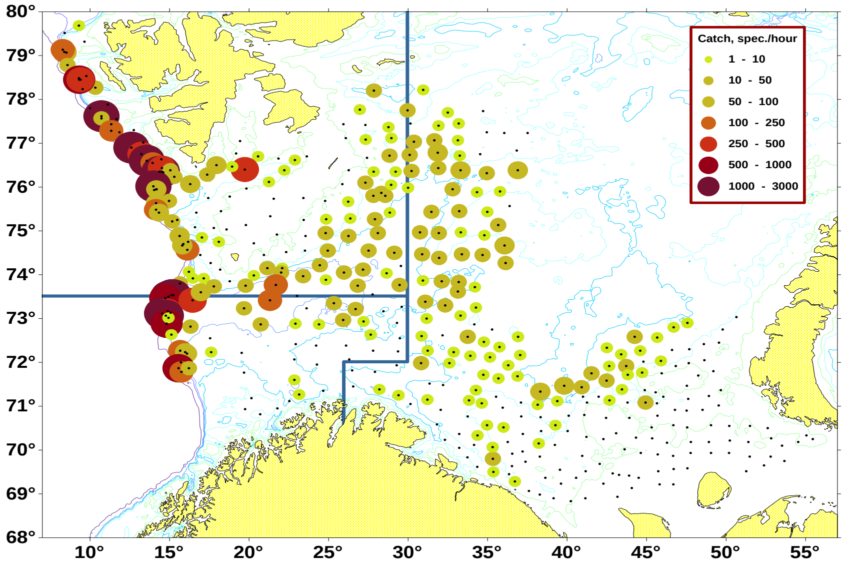


Figure 4.3.45. Greenland halibut distribution in November-December 2012 based on the Russian survey, spec./trawling hour.

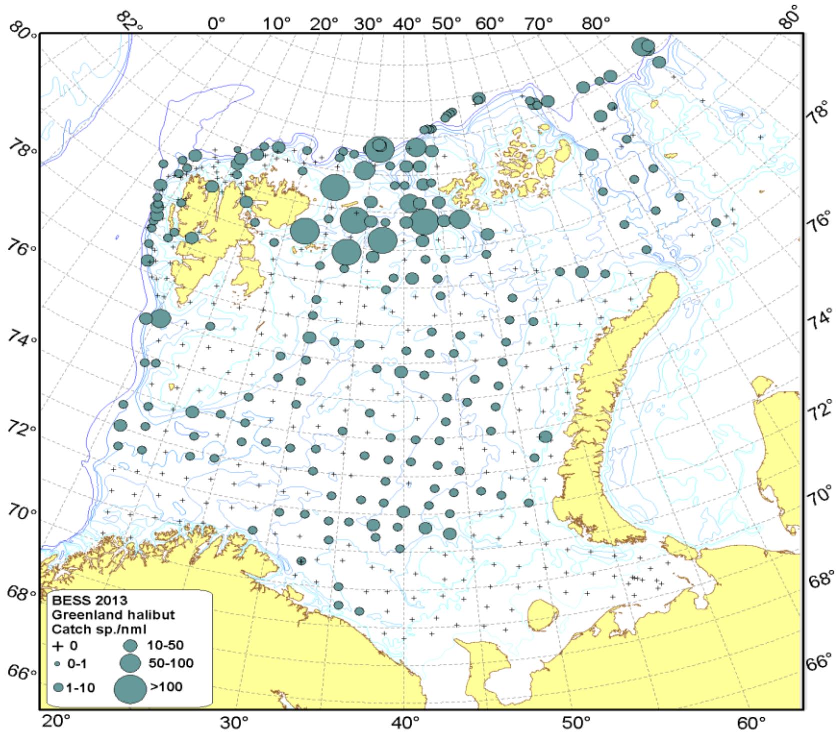
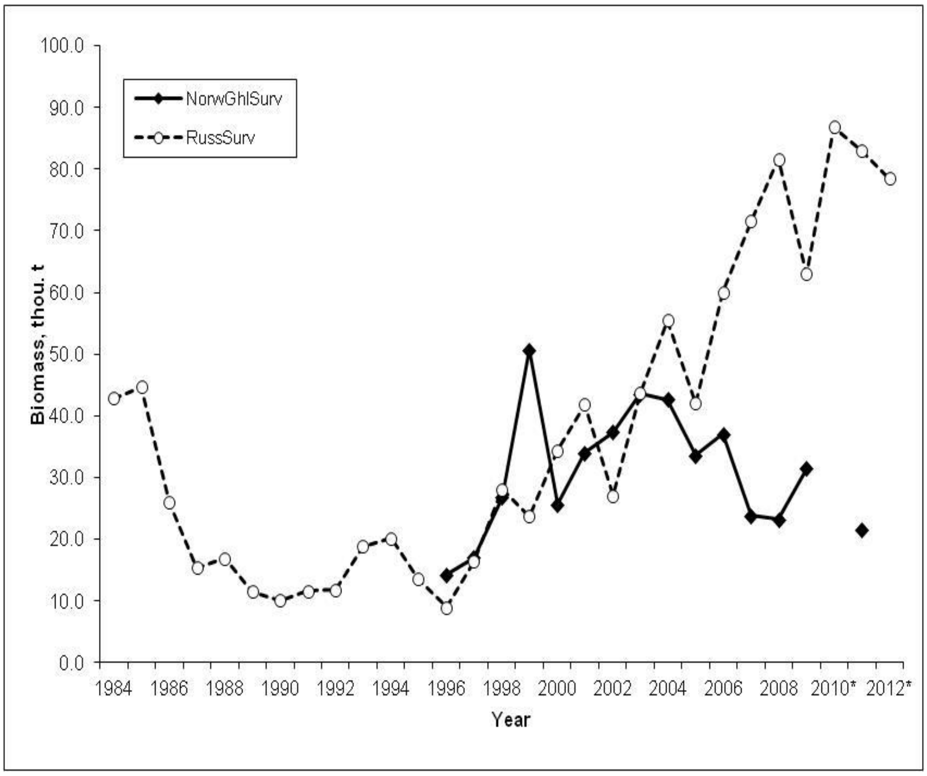


Figure 4.3.46. Greenland halibut distribution in August-October 2013 based on results from the Joint Norwegian/Russian Survey of the Barents Sea Ecosystem, spec./nml.

At present, there is no ICES-accepted assessment for the Greenland halibut stock. This is largely due to age-reading problems and data discrepancies. In the absence of defined reference points, the stock cannot be fully evaluated. This long-lived species can only sustain low levels of exploitation, and the stock has been at low to intermediate levels of abundance for several years. Despite some signals in recent years that the stock may be increasing, indications from different fishery-independent surveys are inconsistent (Figure 4.3.47) (ICES AFWG, 2014).



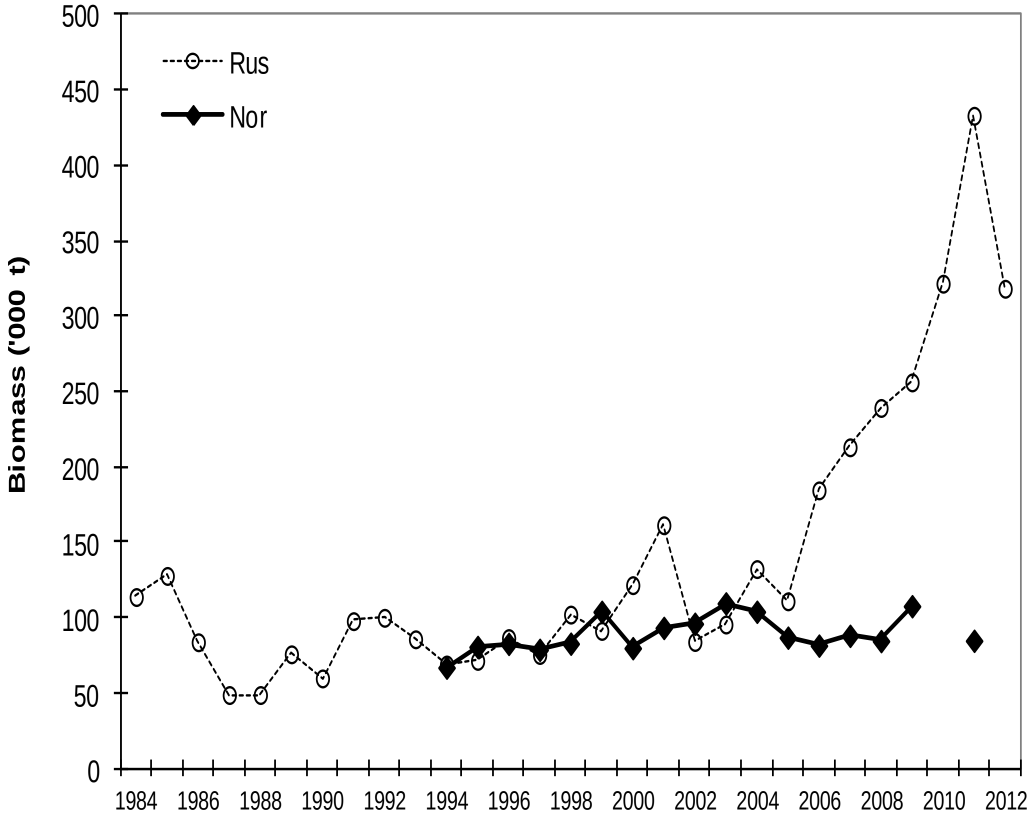


Figure 4.3.47. Northeast Arctic Greenland halibut.
Upper: Biomass (swept area) estimate of the mature female biomass (Norwegian Greenland halibut survey along the continental slope in August and Russian autumn trawl survey).
Lower: Total biomass estimates from the Norwegian Greenland halibut survey along the continental slope in August and Russian autumn trawl survey. No Norwegian survey was conducted in 2010 or 2012.

4.3.6.5 Wolffish *(Anarhichas sp.)*

Three species of wolfish — Atlantic wolffish (*Anarhichas lupus*), Spotted wolffish (*Anarhichas minor*), and Northern wolffish (*Anarhichas denticulatus*) — live in the Barents Sea. The abundance and biomass of all three species is relatively low (Figure 4.3.48), but they are all widely distributed throughout the Sea. The stock size of Atlantic wolffish and spotted wolffish, as measured by area-swept-clear estimates, has been relatively stable since 2004; the Northern wolffish has varied between 35,000 and 90,000 tonnes. Area-swept-clear estimates of stock size are based results from the Joint Norwegian/Russian Survey of the Barents Sea Ecosystem (ICES AFWG, 2014).

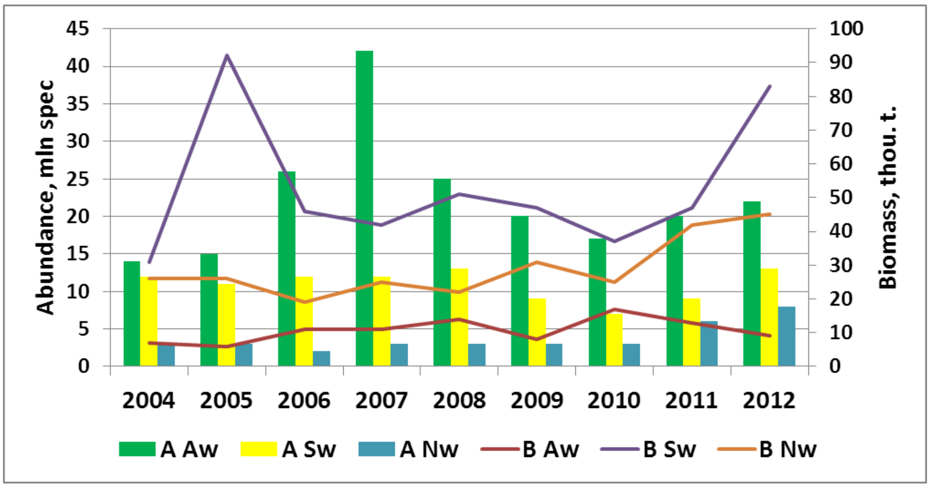


Figure 4.3.48. Stock abundance (A) and stock biomass (B) of Atlantic wolffish (Aw), Spotted wolffish (Sw) and Northern wolffish (Nw) during the ecosystem survey 2004-2012, calculated using bottom trawl estimates (swept area).

4.3.6.6 Capelin *(Mallotus villosus)*

Capelin stock size has been stable since 2008 (Figure 4.3.49). Spawning stock size in 2014 was predicted from September-October 2013 acoustic survey data in combination with results from a model — estimating maturity, growth, and mortality (including predation by cod). The model accounts for uncertainties in both survey estimates and other input data. At catch levels below 65,000 tonnes (during spring 2014), the probability of SSB falling below 200,000 tonnes was less than 5 %. Thus, the 2014 TAC was set at 65,000 tonnes, in accordance with the harvest control rule (ICES AFWG, 2014).

Based on the most recent estimates of SSB and recruitment, ICES classifies the stock as having full reproductive capacity. The maturing component in autumn 2013 was estimated to be 1.5 million tonnes, and SSB 1st April 2014 was predicted to be at 0.4 million tonnes. The spawning stock in 2014 will consist of fish from the 2010 and 2011 year classes; but the 2010 yearclass will dominate. The estimated 2012 yearclass based on survey data, is above the long-term average. Observations during the international 0-group survey in August-September 2013 indicate that the 2013 yearclass is of average size. The estimated annual consumption of capelin by cod has varied between 0.2 and 4.1 million tonnes over the period 1984-2012. Young herring consume capelin larvae, and this predation pressure is thought to be one of the causes for the poor year classes of capelin in the periods 1984-1986, 1992-1994 and 2002-2005 (ICES AFWG, 2014).

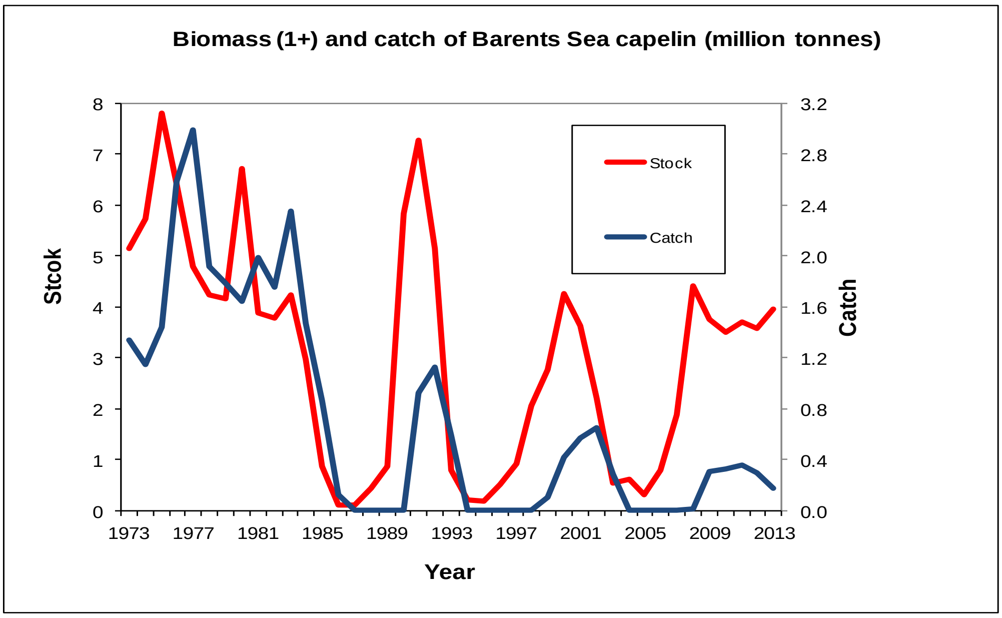


Figure 4.3.49. Barents Sea capelin. Total stock (1+) and total landings, 1973–2013.

4.3.6.7 Herring (*Clupea harengus*)

Based on the most recent estimates of SSB and fishing mortality, ICES classifies the stock as having full reproductive capacity and being harvested sustainably. The 2002 and 2004 year classes dominate the current spawning stock which is estimated to be 5 million tonnes in 2013. The year classes 2005-2012 are all below average, while the 2013 year class is around average. The abundance of herring in the Barents Sea is believed to be at an intermediate level in 2014. This stock has shown a large dependency on the occasional appearance of very strong year classes (Figure 4.3.50). Norwegian spring-spawning herring is fished along the Norwegian coast and in the Norwegian Sea, but not in the Barents Sea. However, juveniles from this stock play an important part role in the Barents Sea ecosystem (ICES AFWG, 2014).

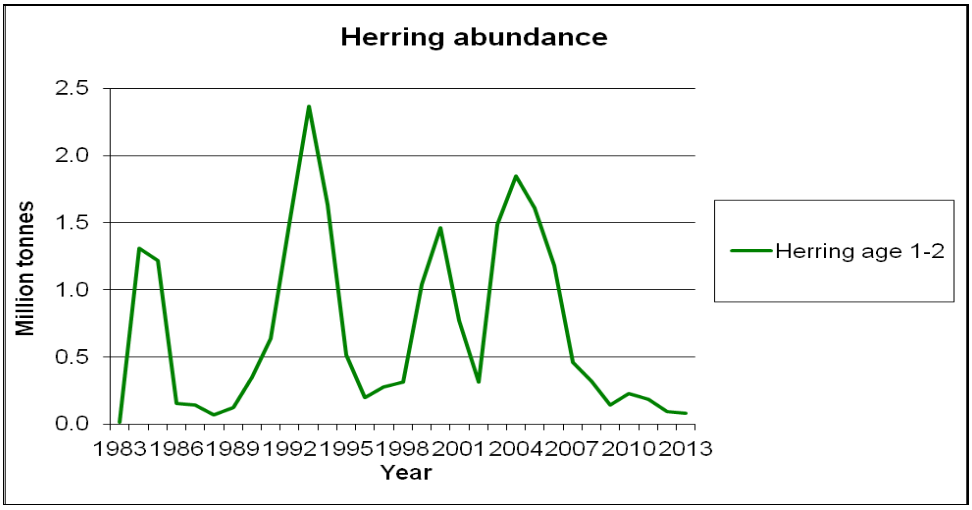


Figure 4.3.50. Abundance of age 1 and 2 Norwegian Spring-spawning herring (calculated by VPA). This is a good indication of the abundance of young herring in the Barents Sea.

4.3.6.8 Polar cod (*Boreogadus saida*)

The polar cod stock is presently at a low level of abundance (Figure 4.3.51). Norway conducted commercial fisheries for this species during the 1970s; Russia has fished this stock on a quite regular basis since 1970. Nevertheless, for many years the fishery has been so small that it is believed to have little impact on stock development. Stock size has been measured acoustically since 1986, and has fluctuated between 0.1-1.9 million tonnes. The 2013 stock size was estimated to be approximately 0.5 million tonnes, roughly the same estimate as in 2012. The rate of natural mortality for this stock appears to be very high. This is likely due to the importance of polar cod as prey for cod and various seal populations (ICES AFWG, 2014).

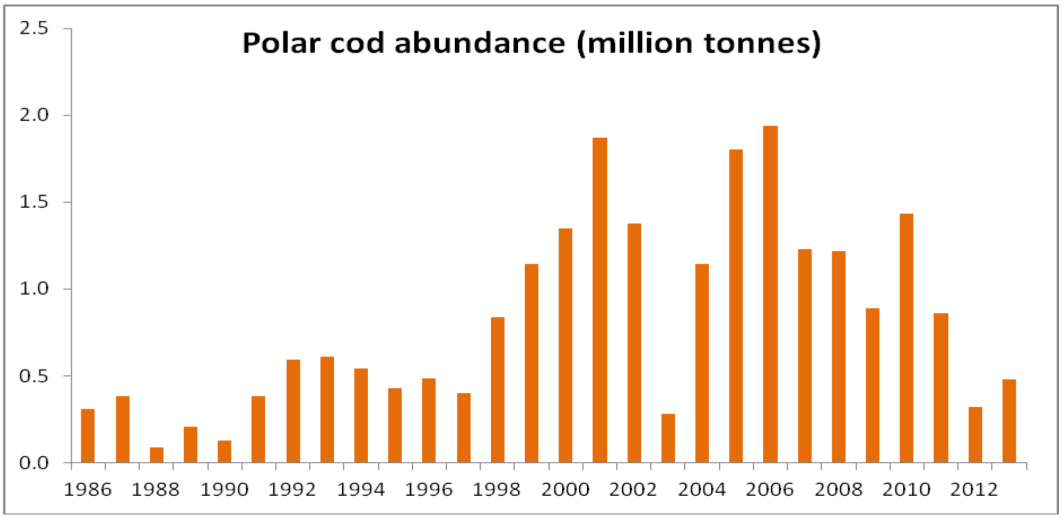


Figure 4.3.51. Polar cod stock size estimates obtained by acoustics, 1986–2013.

4.3.6.9 Blue whiting (*Micromestisius poutassou*)

Based on the most recent estimates of fishing mortality and SSB, ICES classifies the stock as having full reproductive capacity and being harvested sustainably. SSB increased to a historic high in 2003, and then decreased; there is evidence, however, that SSB is now increasing again. Blue whiting is not fished in the Barents Sea; however a TAC is set for the entire Northeast Atlantic region. Total landings in 2012 were estimated at 384,000 tonnes. The 2013 TAC was set at 643,000 tonnes, while the TAC advice for 2014 is 949 000 tonnes (ICES AFWG, 2014).

High abundance of blue whiting observed in the Barents Sea during 2004-2007 (Figure 4.3.52) may be due to increased temperature and high levels of recruitment. Blue whiting has been observed in the western and southern Barents Sea for many years, but never in such quantities, and never in areas as far north and east as during 2004-2007. Subsequently, abundance decreased to very low levels during 2008-2011, but again increased upon recruitment of the 2011 yearclass (ICES AFWG, 2014).

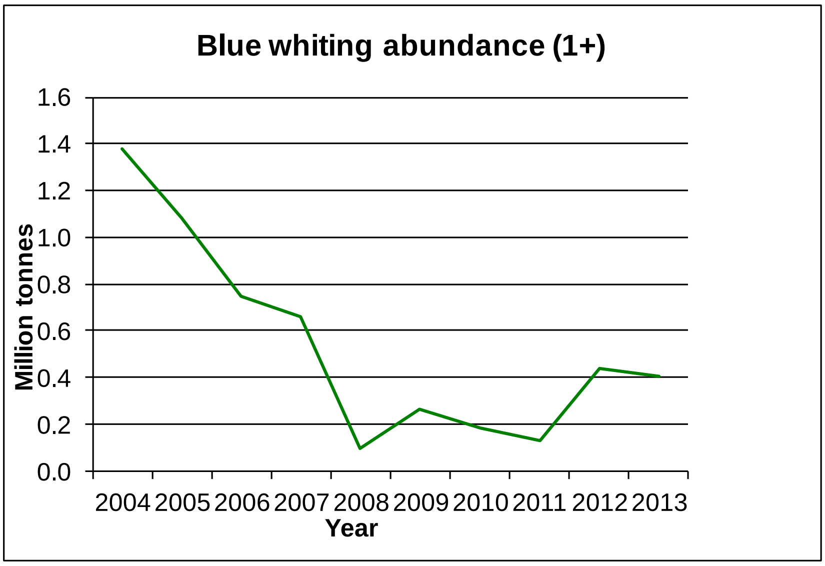


Figure 4.3.52. Blue whiting. Acoustic abundance estimates from the ecosystem survey autumn 2004-2013

4.3.6.10 Saithe (*Pollachius virens*)

The 2013 saithe assessment was not accepted by ICES, but national advice was provided to Norwegian authorities by IMR. SSB has decreased in recent years, and fishing mortality has increased (Figure 4.3.53). The 2014 TAC was set at 119,000 tonnes based on national advice; this represents a 15% reduction from 2013 (ICES AFWG, 2014).

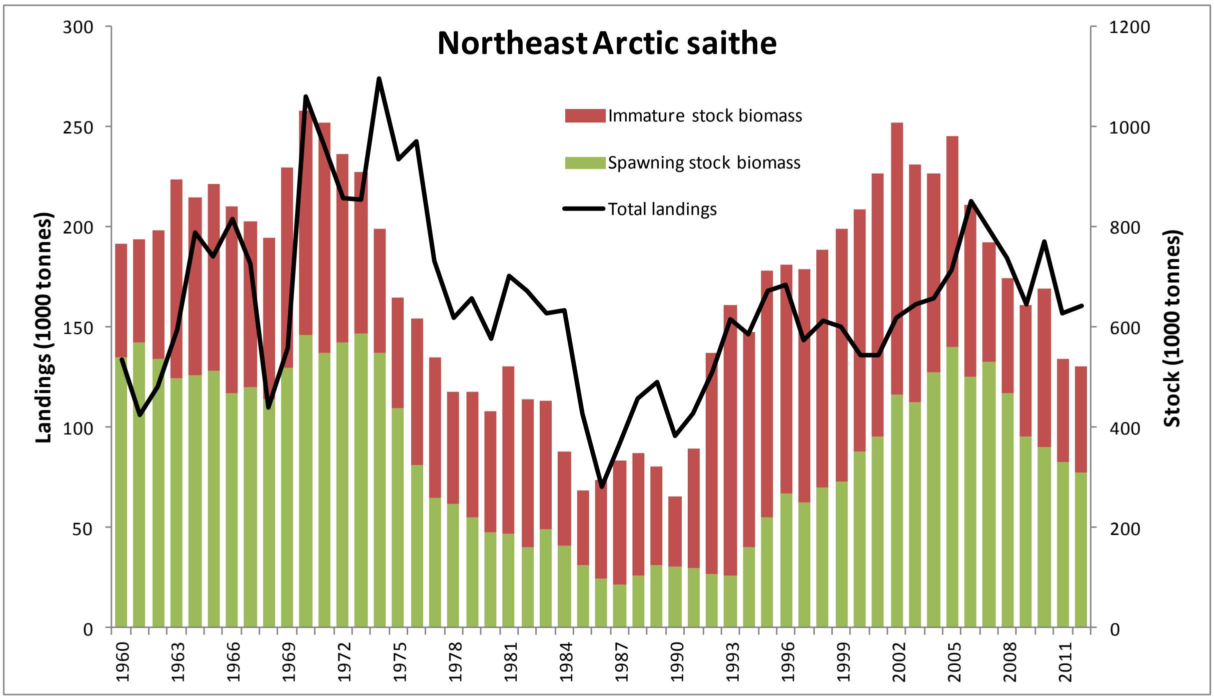
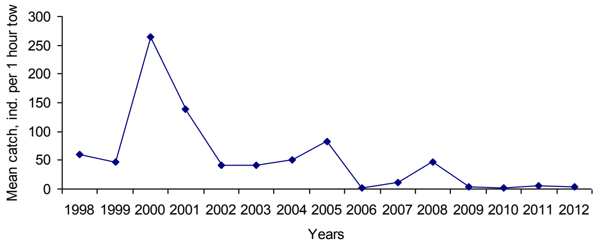


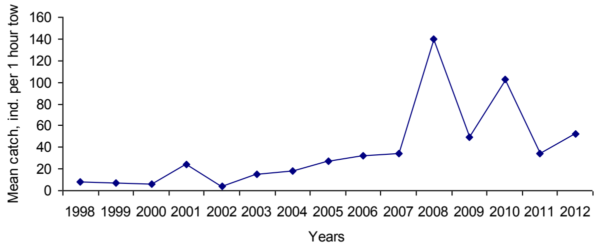
Figure 4.3.53. Northeast Arctic saithe, development of spawning stock biomass (green bars), immature stock biomass (age 3 and older, red bars) and landings (black curve).

4.3.6.11 Trends in the Barents Sea fish community

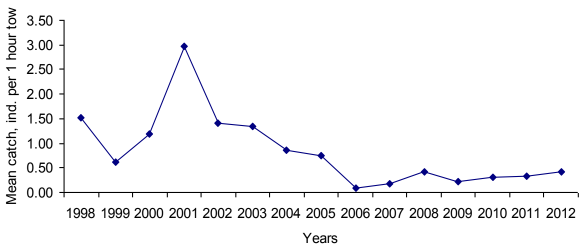
During the recent warming period (1998-2012), distinct trends were observed in abundance of fish species from different zoogeographic groups (Figure 4.3.54). The abundance of coldwater fish species (arctic, mainly arctic, and arcto-boreal) decreased during the period between 2000 and 2010. However, a trend of slight increase has been observed since 2010 in the abundance of mainly arctic and arcto-boreal groups.



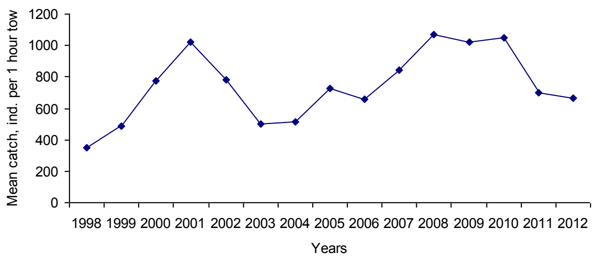
Arctic



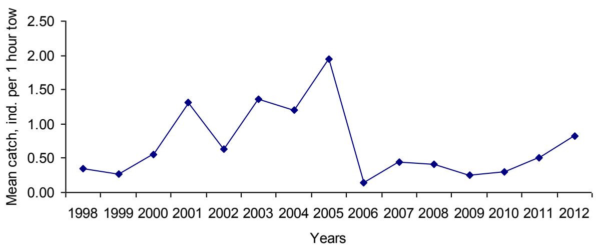
Boreal



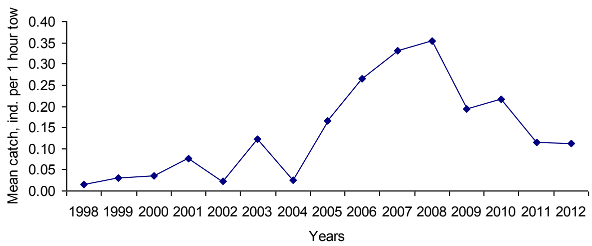
Mainly Arctic



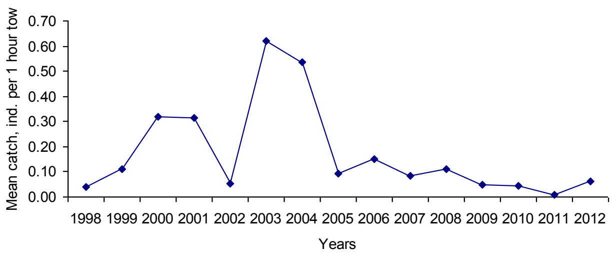
Mainly boreal



Arcto-boreal



Southern boreal



Widely distributed

Figure 4.3.54 Changes in abundance of fish species from different zoogeographic groups in the Barents Sea in 1998-2012 based on the data from Russian autumn-winter demersal survey in October-December.

In contrast, during this same warming period (1998-2012), an overall trend of increasing abundance has been observed in groups of warm-water fish species (boreal, mainly boreal, southern boreal). Since 2006-2008, however, a trend of decreasing abundance has been observed for all these groups (ICES AFWG, 2014).

4.3.7 Marine mammals

J. Aars (NPI), S. Belikov (VNIIPriroda), A.K. Frie (IMR), K. Kovacs (NPI), R. Klepikovsky (PINRO), M. Skern-Mauritzen (IMR), and V. Svetochev (MMBI)

All Arctic-endemic marine mammals in the Barents Sea (polar bear, walrus, ringed seal, bearded seal, harp seal and hooded seal, white whale, narwhal and bowhead whale) are associated with sea ice throughout much or all of their annual cycle. Hence, they are all currently a conservation concern (e.g. Tynan and DeMaster, 1997; Stirling et al., 1999; Kovacs, 2004; Derocher, 2005; Belikov, 2008; Wiig et al., 2008; Kovacs and Lydersen, 2005, 2008; Kovacs et al., 2011a, 2012) because of the declines in Arctic ice coverage over recent decades, that have been particularly acute in the Barents Region (see Laidre et al., 2015).

4.3.7.1 Polar bears (*Ursus maritimus*)

Polar bears have a circumpolar Arctic distribution, which includes the entire northern Barents Sea south to Novaya Zemlya. They are heavily dependent on sea ice for foraging and for travelling to and from terrestrial denning areas; they depend on thick layers of snow in maternity denning areas. They prefer first-year ice that develops over shelf seas for hunting, where ice-associated seals (their primary prey) are most abundant (Derocher et al., 2002). Coastal land-fast sea ice is particularly important to mothers with young cubs when they emerge from their dens in the spring (Freitas et al., 2012). Nineteen polar bear populations are currently recognised, varying in size from a few hundred to a few thousand animals; the global population size is ≈26,000 animals (IUCN, 2015). The Barents Sea population, which extends from Svalbard eastwards to Franz Josef Land, is genetically distinct from polar bears in east Greenland and elsewhere. Satellite telemetry has documented routine movements of some bears throughout the entire Barents Sea region (Mauritzen et al., 2002), confirming genetic analyses that suggested there is no geographic distinction between animals from Svalbard and Franz Josef Land (Paetkau et al., 1999; Zeyl et al., 2009; Peacock et al., 2015). Polar bears were exploited in the Barents Region from the late 18^{th} century onward (Uspensky, 1969; Lønø, 1970; Prestrud and Stirling, 1994). Following extreme overexploitation of the stock, hunting was banned in 1956 in Russia and in 1973 in Norway.

The first population survey, in 2004, estimated that ~2,650 (95% CI 1,900-3,550) bears reside in the northern Barents Sea (Table 4.2.2, Aars et al., 2009); population trends are currently unknown, but a second survey was flown within Norwegian territory in the northern Barents Sea in 2015 which will provide a new estimate. Population declines are expected in coming decades for most polar bear populations, including that in the Barents Sea because of declining sea ice conditions (e.g. Wiig et al., 2008; Durner et al., 2009; Hunter et al., 2010). In Svalbard, polar bear body condition has not changed over recent decades, nor has the number of cubs-of-the-year per adult female or the number of yearlings per adult female (MOSJ, unpublished data).

4.3.7.2 Walruses (*Odobenus rosmarus*)

Walruses are distributed across the circumpolar Arctic, but their distribution is discontinuous and two subspecies are recognized: one in the Pacific; and the other in the Atlantic. In the northern Barents Sea, they are found from Svalbard through to Franz Josef Land; in the southern Barents Region, they occur in the Pechora Sea and the Kara Sea. Recently, they have been observed regularly in the White Sea as well (Klepikovsky and Lisovsky, 2005; Svetochev and Svetocheva, 2008; Zyryanov et al., 2008). Walruses also occur in the Laptev Sea, but a recent genetic study confirms that these animals belong to the Pacific subspecies (Lindqvist et al., 2009). Walruses in the northern Barents Sea comprise a single population of Atlantic walruses that occupies the ice between the two archipelagos during the winter mating period (Lowther et al., 2015), although individual animals seem to display considerable fidelity to their respective summering grounds (Freitas et al., 2009). The affinity of animals from the Pechora, Kara and White Seas is currently under investigation. Walruses are generally found in shallow water areas (<80 m) with suitable bottom substrate that can support a highly-productive bivalve community within reasonably close proximity to suitable haul-out areas (land or ice). However, they can occasionally be found on ice over very deep areas (NPI Marine Mammal Sighting Data Base; Gorbunov and Belikov, 2008). Walruses were dramatically overharvested in Svalbard in the 1800s and early 1900s, with only a few hundred remaining when they became protected in 1952. Walrus populations were also depressed by hunting in southern parts of the Barents Sea, extirpating them from the Norwegian mainland and reducing them throughout the Pechora and Kara Seas. Franz Josef Land was occasionally visited during this early hunting period, but its isolation meant that it was less impacted than Svalbard. Most walruses in Svalbard are males, but the number of sites occupied by females and calves is increasing (Lydersen et al., 2008; Kovacs et al., 2014). There are approximately 20,000 Atlantic walruses (Stewart et al. 2014), so the Barents Sea represents an important region for this subspecies. Walrus abundance in the Barents Sea has definitely trended upward in recent decades; the rate of increase cannot be accurately assessed however, due to a lack of trend data for Russian sectors, especially Frans Josef Land. Data from only a single aerial survey is available for the Pechora Sea (Lydersen et al., 2012a). However, walruses in southern Russian territories of the Barents Sea are believed to be increasing based on shipping observations (Svetochev and Svetocheva, 2008; Zyryanov et al., 2008; Chernook et al., 2012). There is concern for animals occupying this region due to oil and gas development; available information on the ecology of the Atlantic walruses in the southeastern Barents Sea and adjacent regions is summarized in Boltunov et al. (2010).

4.3.7.3 Ringed seals (*Pusa hispida* or *Phoca hispida*)

Ringed seals occur throughout the Arctic. They are the only northern seal that can maintain breathing holes in thick sea ice and thus are distributed well beyond the range of the other northern true seals – north to the Pole (Heide-Jørgensen and Lydersen, 1998; Gorbunov and Belikov, 2008). They are extremely dependent on sea ice, which is their exclusive breeding and haul-out platform. Typically, they prefer land-fast ice in fjords and along coastlines, with reasonably thick and stable snow cover (e.g. Lydersen and Gjertz, 1986); but, they also live and breed in drifting pack-ice in the Barents Sea (Heide-Jørgensen and Lydersen, 1998). Ringed seals remain associated with ice yearround (Freitas et al., 2008a; Hamilton et al., 2015). Their distribution and movements in summer are likely driven by food availability (primarily pelagic and ice-associated prey) in combination with sea-ice conditions (Freitas et al., 2008b; Eliseeva, 2008). The world population of ringed seals is believed to number in the millions, but few areas have been surveyed systematically, and climate change is clearly a major threat to this species. Within the Barents Sea, assessment data are only available from some of Spitsbergen’s fjords, where the west/north coast stock consisted of 7,000-10,000 animals (Krafft et al., 2006) in the early 2000s. No recent surveys have been conducted in Svalbard, and Frans Josef Land has never been assessed, nor has the Barents Sea pack-ice. Ringed seal reproduction has likely been negatively impacted during recent years with poor ice conditions in Svalbard (2006-2015); reduced habitat available for pupping is also likely to cause declines in the adult population. Redistribution and declines in abundance are expected based on forward-looking sea-ice scenarios for the Barents Region (e.g. Freitas et al., 2008b; Kovacs and Lydersen, 2008). Monitoring plans have recently been developed, but not yet implemented. Aerial surveys have been conducted for ringed seals in the White Sea, but recent results are not yet available.

4.3.7.4 Bearded seals (*Erignathus barbatus*)

Bearded seals have a patchy distribution throughout the Arctic, occurring at low densities throughout their range. They are largely solitary, but small groups can be seen during late spring-early summer when they breed and then moult/molt, and the sea-ice cover is limited. Bearded seals can maintain holes in relatively thin ice, but avoid densely packed ice unless open-water leads are available. During winter, they may concentrate near polynyas, in areas where leads are frequent, or near the edges of the ice. Some juveniles perform long wanderings (Gjertz et al., 2000) and can be found far south of the normal adult range. Similar to walruses, bearded seals forage mainly on benthic organisms (Hjelset et al., 1999; Hindell et al., 2012). Therefore, they prefer to reside in drifting pack-ice over shallow water. They are largely coastal animals; but because the Barents Sea is generally quite shallow, they can be found in drifting pack-ice far from the shore. While bearded seals in some areas are believed to have a small home range of distribution throughout the year (e.g. Eliseeva, 2008), seals in other areas are believed to follow the retracting ice northward during summer and return southward again during late autumn and winter. Bearded seals are hunted at low levels in Svalbard and in Russian coastal areas. The global population of bearded seals has not been assessed, but this species probably numbers in the hundreds of thousands in the Arctic. In the Barents Sea, there are thousands of bearded seals, but no systematic assessments have been conducted. Declines in sea ice coverage are expected to have negative impacts of bearded seal abundance (e.g. Kovacs and Lydersen, 2008; Kovacs et al., 2011a, 2012). Some ecological studies are available from Svalbard and the White Sea. Also, there are plans to start telemetric studies, but currently no new data is available on distribution or abundance.

4.3.7.5 White whale/beluga whale (*Delphinapterus leucas*)

The white whale/beluga whale is the most numerous of the three resident ice-associated Arctic whales in the Barents Sea. Similar to the other two high-arctic species, it can be found in high concentrations of drifting ice (>90% ice cover) in areas which are inaccessible to migratory species of whales. Satellite-tracking of white whales in Svalbard during summer and early autumn has shown a profoundly coastal distribution; tracking data from late autumn and early winter suggest that they remain close to these coastal areas, penetrating deep into extensive ice. During summer, they spend most of their time close to tidal glacier fronts in Svalbard or moving between them (Lydersen et al., 2001). Presumably, this is due to abundant food in these areas linked to upwelling, or fresh-water osmotic shock to zooplankton which results in fish aggregations that include polar cod (Lydersen et al., 2014); this is thought to be the main food source for white whales in Svalbard (Dahl et al., 2000). Sightings, from the first daylight in March until the last daylight in November additionally, suggest that they remain local in Svalbard on a year-round basis. However, they have not been studied during the dark period, and no assessments have been conducted in Norwegian waters; a survey for this species is planned for 2017 at Svalbard. Aerial surveys and intensive long-term behavioural studies have been conducted on white whales in the White Sea. Some whales are believed to be resident throughout the year; however, there is an influx during summer and an outflux during winter; so some proportion of the White Sea population does migrate into the Kara Sea and the broader Barents Sea during at least part of their annual cycle (Andrianov and Lukin, 2008; Bel'kovich, 2008; Chernetsky and Krasnova, 2008; Glazov et al., 2008; Kuznetsov and Bel'kovich, 2008; Kuznetsova et al., 2008; Nazarenko et al., 2008). Whales in the White Sea tend to concentrate in shallow water areas (<50 m), with the highest densities in summer being found in Onega, Dvina, and Mezenskiy Bays (Glazov et al., 2008; Soloviov et al., 2008). White whales are observed along the south-eastern Barents Sea coast most frequently in May, and least frequently during winter. Stocks have not been well delineated in Russia (Boltunov and Belikov, 2002); but during summer numbers in the White Sea average 5,553 (CI – 15%, Solovyev et al. 2012). Some white whales are believed to migrate from the Barents Sea into the Kara and Laptev Seas during spring after the ice break up, and then to return northward during fall. The global population of white whales has not been accurately assessed, but this species likely numbers in the tens of thousands in the Svalbard/Barents Sea area. Less sea ice will likely result in increased killer whale predation on white whales in northern waters; there also may be changes in prey due to on-going declines in polar cod abundance. But, it is difficult to predict how this species will be affected by climate change given the varied ecological adaptations they display across their range (Gilg et al., 2012).

4.3.7.6 Narwhal (*Monodon monoceros*)

Narwhal inhabit the North Atlantic Ocean sector on both sides of Greenland, as well as Svalbard and Frans Josef Land archipelagos. They also occupy some waters north of Canada and Russia; they are very rare in the Pacific Arctic. Similar to their close relative, the white whale, these mid-sized odontocetes remain in social group (pods) throughout their lives, often in association with sea ice. They are deep divers that feed on Arctic cod, polar cod, Greenland halibut, bottom-dwelling cephalopods, squid, and even shrimp. They may reach over 100 years in age (Garde et al., 2007). Little is known about narwhals in the Barents Sea. They do enter fjords in the north of Svalbard during summer with some regularity, but seem more tightly affiliated with the northern ice than white whales. They occasionally penetrate deeply into west coast fjords, and have been observed during summer along the polar ice edge across the northern Barents Sea, being most numerous near Frans Josef Land (Gjertz, 1991; Gorbunov and Belikov, 2008; NPI Marine Mammal Sighting Data Base). They rarely occur in the southern Barents Sea, but they do occur in the Kara Sea (Gorbunov and Belikov, 2008). Three individuals were observed (satellite-tracked) northeast of Svalbard and remained close to Nordaustlandet in late summer; they sometimes dived deep (maximum 545 m) into a trench in the northeast part of the Svalbard Archipelago (Lydersen et al., 2007). The size of the global narwhal population is not known, but approximately 50,000 individuals are believed to inhabit the Northwest Atlantic region. Likewise, there is no abundance estimate for narwhals in the Barents Sea. They are certainly less numerous than white whales in this area, and are on the Red List for Svalbard, and in the Russian Federation’s Red Book. Laidre et al. (2008) and others suggest that narwhal are likely to be quite sensitive to declining sea ice extent and thickness, and are likely to decline throughout their range in coming decades due to climate change.

4.3.7.7 Bowhead whale (*Balaena mysticetus*)

The bowhead whale is the only baleen whale that resides in the Arctic throughout its life. It is highly adapted to its ice-associated lifestyle, possessing a very thick layer of blubber (up to 30 cm), no dorsal fin, and a complex circulatory system (with numerous vascular adaptations) to conserve heat. Moreover, their elevated blowholes are thought to be an adaptation for breathing within the cracks in sea ice. Compared to the more streamlined species of baleen whales (e.g., the rorqual group, Family Balaenopteridae) the bowhead is a slow swimmer. It is a loosely social species, travelling in small groups most of the time without long-term associations, outside the period of mother-calf pair. Communication among groups is thought to occur over very long distances, because general activity patterns of animals which are spread over a considerable area seem to be coordinated. Among the five recognised stocks of bowhead whales in the Arctic, the Spitsbergen stock occupies the area from the Greenland Sea to Svalbard and across the Barents Sea to Franz Josef Land, and perhaps beyond. Bowhead whales usually remain close to the southern boundary of winter ice; during winter they have been seen in the Kara Sea (Stas Belikov, pers. comm.). Whales in this stock appear to exhibit the same seasonal patterns that were followed during springtime hundreds of years ago, when the population was numerous. As such, they are still found in “Whalers Bay” in the Fram Strait in April (Wiig et al., 2007); some animals inhabiting the Barents Sea migrate southward during summer, and migrate northward again come fall — unlike other populations of this species which exhibit the opposite pattern (Lydersen et al., 2012b).

Extensive overharvesting in the Barents Region during the 1600s-1700s came close to exterminating the bowhead whale population. Their abundance had dropped dramatically in the region by the mid-19th century (Shelden et al., 2001). After WWII, only lone animals or small groups of whales were occasionally observed near the northeastern coast of Greenland, near Spitsbergen, Novaya Zemlya, and Severnaya Zemlya; sightings in Franz Josef Land were slightly more common (Belikov, 1985; Wiig, 1991; Christensen et al., 1992; Moore and Reeves, 1993; Kondakov and Zyryanov, 1994; De Korte and Belikov, 1995). The present number of bowheads belonging to the Svalbard stock is not known, but there is some evidence to suggest that they might be increasing (Wiig et al., 2010; Moore et al., 2012; Stafford et al., 2012; Falk-Petersen et al., 2015). In June 2015, a group estimated to number 85 animals ranging over a few kilometres was sighted by a tourist ship. Distribution and abundance of bowhead whales in the Barents Region in the near future may depend largely on the impact of climate change on the distribution and abundance of calanoid copepods, their primary prey. Their longevity, slow maturity, and low reproductive capacity leave them vulnerable to unfavourable aspects of environmental change (George et al., 1999; Kovacs and Lydersen, 2008). However, some populations of this species are known to be currently increasing in the Bering and Beaufort Seas. Increases in ocean noise are likely to pose a threat to this species that communicates acoustically over significant distances; this suggests that special care should be taken when planning oil and gas exploration and development activities (Reeves et al., 2014).

4.3.7.8 White-beaked dolphins (*Lagenorhynchus albirostris*)

White-beaked dolphins are the only dolphin to remain in the Barents Sea Region on a year-round basis. They are found throughout the North Atlantic, primarily in shelf waters, but they may also inhabit offshore areas of intermediate depths. During summer, they can be found north to the ice edge. They are commonly sighted in coastal waters around Spitsbergen in summer, as well as in the pelagic parts of the Barents Sea, but are most common in the southern Barents Sea in warm Atlantic Water (Skern-Mauritzen et al., 2008). White-beaked dolphins are highly social and occur in groups of 5-50 most of the time. Pods occasionally aggregate into very large groups. They are the most numerous dolphin species in the Barents Sea, with a population size of 60,000-70,000; some 130,000 animals are estimated to inhabit the Northeast Atlantic (Øien, 1993). Barents Sea sighting surveys conducted during the last 5 years, suggest that the distribution and abundance of white-beaked dolphins seem to be quite stable.

4.3.7.9 Harbour seals (*Phoca vitulina*), Grey seals (*Halichoerus grypus*), and Harbour porpoise (*Phocoena phocoena*)

Coastal marine mammal species in the Barents Sea include harbour seals, grey seals, and the harbour porpoise. Larger whales also migrate along the coast on their way north to the take advantage of the summer burst of productivity in the Barents Sea. The harbour seal is a coastal species that is found both in the Atlantic and Pacific Oceans. Harbour seals are gregarious, hauling out to rest on land at low tide every day of the year, in groups ranging from just a few animals up to a few hundred. The number of individuals hauling out on land is dependent on the tidal phase and height, season, weather conditions, etc. (e.g., Reder et al., 2003; Merkel et al., 2013). Although they commonly shift their favoured haul-out places depending on the season, harbour seals are not truly migratory. For the most-part harbour seals are a temperate species, which occurs as far south as California in the Pacific, Maine in the West Atlantic, and southern Europe in the East Atlantic. But harbour seals also occur, albeit in low numbers in the Barents Sea, along the north Norwegian coast across the border to 39oE, in the region of Ivanovskaya and Saviha Bays. Harbour seals have also been observed in recent years in the White Sea, in both Dvinsky Gulf and Onezhsky Gulf (Vladimir Svetochev, pers. comm.). There is also a small group of harbour seals in Svalbard that is largely restricted to the west coast of Spitsbergen within the Svalbard Archipelago (Blanchet et al., 2014, 2015; Hamilton et al., 2014). The Svalbard stock consists of ~2,000 animals (Merkel et al., 2013); a similar number is found along the Troms and Finnmark coasts (Nilssen et al., 2009). Additionally, some 400-500 animals are found along the Murman Coast (Zyryanov, 2000). Although widely distributed, harbour seals occur at low densities throughout their broad range. The Norwegian coastal stock is hunted in a licensed game hunt; this stock also is subject to mortality via entanglement in gill nets and other fisheries-related mortality. Up until 2010, harbour seals were subjected to unsustainable hunting pressures in many areas along the Norwegian coast including parts of northern Norway. However, surveys conducted in 2011-2014 indicate a small increase in the harbour seal population on the Norwegian mainland, including a small local increase in Troms and Finmark resulting from hunting restrictions. There is still a legal quota-regulated sports hunt for harbour seals, but quotas are now set according to a management plan to ensure that viable harbour seal colonies exist throughout their present areas of distribution. There is concern over potential bycatch levels in some areas; data collected by the Norwegian coastal reference fleet are currently being analysed to estimate the extent of bycatch. Recent observations of killer whale predation on harbour seals along the Norwegian coast also suggest that natural mortality rates may be increasing for this species.

Grey seals occur only in the North Atlantic, south to Maine in the western Atlantic and to the Baltic Sea in the eastern Atlantic. Major population centres are located around the British Isles and on Sable Island off the east coast of Canada. Baltic and Norwegian grey seal populations are genetically different, as are populations in eastern and western Atlantic regions. Subpopulations within the Barents Sea Region also show significant genetic variation (Frie and Kondakov, 2008). Although larger than harbour seals, grey seals share their coastal habitat, but they spend longer periods at sea during parts of the year. This species utilises a wide variety of habitats. Within most of its range, it breeds on land; but it also uses land-fast ice and free-floating pack-ice when accessible — such as in the Gulf of St Lawrence on the east coast of Canada — for hauling out and giving birth during winter (e.g. Tinker et al., 1995). Within the Barents Sea, grey seals occur along the north coast of mainland Norway, and eastward along most of the Murman coast; they are occasionally observed in the White Sea during summer, and have been documented in the Pechora Sea during aerial surveys for walrus (Lydersen et al., 2012a). They have been heavily harvested in the past, being reduced to just 2 breeding locals and very low numbers during the 1950s in northern regions, e.g., only 500-600 animals in Lofoten (Øynes, 1964). Hunting at breeding colonies was prohibited in Norway in 1973. Only 200 pups were produced in Troms and Finnmark in 2003 (Nilssen and Haug, 2007). However, the number of grey seals along the coast of Finmark is likely larger than would be predicted based on the local breeding populations, as Russian seals undertake feeding migrations to Norwegian waters. During 2003-2010, grey seal hunting quotas were set at 25% of regional population abundance; annual removals of around 20% were occurred during this period. Nevertheless, pup production in Troms and Finmark appeared to have increased, suggesting that a large proportion of the removals were not local seals. After 2010, removals have gone down drastically in Northern Norway, due to reductions in quotas and elimination of government bounties. Quotas are now set according to a national management plan for grey seals, which aims to secure viable local populations within their current range. Grey seals were Red Listed in Russia in 1978 and have remained protected since that time. The grey seal colonies on the Murman Coast were last surveyed with pup counts in the early 1990, 1991 and 1994 – the results indicated a minimum population size of 3000-3500 animals (Haug et al., 1994b; Ziryanov and Mishin, 2007).

The harbour porpoise is a small odontocete with a wide geographic range that includes most temperate and boreal waters of the Northern Hemisphere. Two or three morphologically distinct subspecies are known to occur in the Atlantic and Pacific Oceans. It is the smallest cetacean in the Barents Sea, and is largely a coastal species; although sometimes seen in deep areas, harbour porpoises prefer shallow, inshore waters. A single harbour porpoise was sighted repeatedly on the north coast of Spitsbergen over 2005-2007 during summer, often in association with groups of white whales (NPI Marine Mammal Sighting Data Base; Kovacs and Lydersen, 2006). This species normally occurs in small groups and only rarely forms larger aggregations. Onshore-offshore migration is thought to take place regularly, albeit over limited distances. Harbour porpoises live year-round in the southern Barents Sea, and in fjords along the coast of Norway. They tend to be tightly coastal in the western part of their range in the Barents Sea; while in the east they are found along banks sometimes quite far from shore — such as the Kanin and Goose Banks (Skern-Mauritzen et al., 2008). Based on observations made during minke whale surveys, the offshore component of the Barents Sea harbour porpoise population is believed to consist of about ~11,000 individuals (Bjørge and Øien, 1995). No data are available for the nearshore areas where density is expected to be highest. Harbour porpoises are caught accidentally in coastal gill-net fisheries to an extent thought to be unsustainable on a local scale, e.g., the Vestjord area (Bjørge et al., 2013). To sustain current levels of by-catch, immigration of porpoises from adjacent waters is required in this region. The future situation is difficult to predict because migration patterns, population structure, and the general ecology of harbor porpoises in Norwegian coastal waters are not well documented (Bjørge, 2003).

4.3.7.10 Harp seals (*Pagophilus groenlandicus*)

Harp seals are migratory and have a much wider distribution range than ringed seals, bearded seals, and walruses; they also have a more pelagic life history (Lavigne and Kovacs, 1988; Haug et al., 1994a). Three different populations inhabit the North Atlantic: the Northwest Atlantic population off Canada's east coast; the Greenland Sea (West-Ice) population which breeds and moults just north of Jan Mayen; and the East-Ice population which congregate in the White Sea to breed. During spring (February-April), harp seals whelp on pack ice and then adults and subadults moult north of each respective whelping location after a lapse of ~4 weeks. Within the West-Ice population, these events occur primarily at fringes of the winter ice on the seaward side of thicker ice off the east Greenland pack (69-75 °N). Within the East-Ice population, these events occur in the White Sea and the south-eastern Barents Sea. When the moult is over, the seals disperse in small herds, feeding heavily to restore their blubber reserves. Some individuals from both Northeast Atlantic populations spread into the Barents Sea during summer and autumn months overlapping their ranges; their specific distribution in the Barents Sea mainly depends on the distribution of drifting pack-ice (Folkow et al., 2004; Nordøy et al., 2008). The body condition of animals that summer in the northern Barents Sea has recently declined (Øigard et al., 2013), presumably because of competition for food or changes in prey abundance. The West-Ice seals also spread through the drift ice along the east coast of Greenland, from Denmark Strait or farther south, towards Spitsbergen. The southward migration towards the breeding areas begins in November-December. The West-Ice and East-Ice populations have been commercially exploited and managed jointly by Norway and Russia over the past two centuries. The most recent estimate for the West-ice group is ~630,000 (ICES WGHARP, 2014) and the population is thought to be stable or increasing (ICES WGHARP, 2014). The Russian White Sea population has been monitored a long time; Dorofeev (1939, 1956), reported that aerial surveys performed on moulting grounds in 1927-1928 suggested that the White Sea population size at that time may have been 3.0-3.5 million individuals. While exploitation was low during World War II, the total hunting pressure increased substantially from 1946 onward (ICES WGHARP, 2008), and the population was probably reduced to 1.25-1.5 million individuals by the 1950s based on aerial surveys on the moulting grounds during 1952-1953 and 1959 (Surkov, 1957, 1963; Skaug et al., 2007). More recent pup production has been in decline, dropping from over 300,000 in during 1998-2003 to 123,000 in 2008 (ICES WGHARP, 2008). Reasons for the decline are not known, but it has been suggested that factors such as climatic conditions altering the ice cover in the White Sea, industrial activity including shipping and pollution effects, competition for krill and fish resources (i.e., capelin declines), and excessive hunting levels may all be contributing factors (Chernook and Boltnev, 2008; Chernook et al., 2008; Shafikov, 2008; Vorontsova et al., 2008; Zabavnikov et al., 2008; Øigård et al., 2013).

4.3.7.11 Hooded seals (*Cystophora cristata*)

Hooded seals form one stock in the Northwest Atlantic and another in the Northeast Atlantic; although, recent genetic studies suggest no biological distinction between the groups (Coltman et al., 2007). In the Northeast Atlantic, whelping takes place in mid-late March in the West Ice, not far from where the West-Ice harp seals give birth. Between breeding and the moult, hooded seals carry out feeding excursions to the continental shelf edge off the Faroe Islands and Northern Ireland and to areas in the Norwegian Sea. During moult in June-July, the West Ice stock hauls out on pack-ice north of Jan Mayen. According to satellite-tracking data, seals from this stock occupy ice-covered waters off the east coast of Greenland much of the summer. They also make excursions to the Faroe Islands, the Irminger Sea, north/northeast of Iceland, the Norwegian Sea, along the continental shelf edge from Norway to Svalbard, and into the Barents Sea, presumably to feed in areas of high productivity caused by the upwelling at the shelf and ice edges (Folkow et al., 1996; Kovacs et al., 2011b). During summer excursions, which can last for more than 3 months, the seals apparently never haul out, not even in coastal areas. But, they are seen on land-fast ice and on floes in the Svalbard region from early spring to late autumn (Kovacs and Lydersen, 2006). The number of hooded seals occupying the Svalbard area and entering the Barents Sea is likely to vary from year to year, depending on ice conditions. Hooded seals of the West-Ice stock have been commercially exploited since the mid 1800s and are managed jointly by Norway and Russia. Back-calculation using a population model indicate a possible stock size of 700,000 animals in the West Ice shortly after WWII, while stock size was estimated to be ~82,000 animals in 2007 (ICES WGHARP, 2008). Because of significant declines, this species is now on the Norwegian Red List and the quota has been set to zero since 2007 (ICES WGHARP, 2014).

Similar to other ice-dependent marine mammals of the Barents Sea region, harp and hooded seals are expected to decline with reductions of sea ice in the coming decades (e.g. Kovacs and Lydersen, 2008; Kovacs et al., 2011a, 2012). It has been suggested that reduced body condition of Barents Sea harp seals, observed since 2004, may be partly due to increased distance between breeding areas in the White Sea and summer feeding areas at the ice edge in the Barents Sea (Bogstad et al., 2015). Increased resource competition with a record-large cod stock in the Barents Sea may also be a factor. Although harp seal pup production in the West Ice has not declined, a marked increase in mean age at maturity from the early 1990s to 2009 suggests that these seals are also experiencing reduced habitat quality. The registered declines in West Ice hooded seals and White Sea harp seals — along with harp seal condition declines in summer in the northern Barents Sea — are believed due, in part, to changes in ice distribution and other ecosystems shifts related to climate warming (Bogstad et al., 2015; Kovacs et al., 2011a, 2012).

4.3.7.12 Pilot whales (*Globicephala melas*); Sperm whales (*Physeter macrocephalus*); and Northern bottlenose whale (*Hyperoodon ampullatus*)

Among the toothed whales, the long-finned pilot whale, sperm whale, the northern bottlenose whale, and killer whales are summer visitors to the Barents Sea. The Northeast Atlantic population of long-finned pilot whales number some 780,000 individuals (NAMMCO 1998), but only a very small (and unknown) part of this population enters the Barents Sea. Few sightings have been made in areas covered by IMR surveys; these sightings are insufficient to estimate abundance, but they demonstrate high variability in the number of individuals encountered from year to year. Pilot whales must therefore be considered stragglers along the Norwegian coast and in the Barents Sea, although significant sized pods are occasionally seen as far north as Bjørnøya. Sperm whales are associated with deeper areas along the shelf edge north to Spitsbergen, but are occasionally observed north to the ice edge, on the shelf and occasionally also in the fjords of Svalbard. Although the northern bottlenose whale is a deep water species, individual animals are observed annually by the Russian fishing fleet in the western part of the Barents Sea during the summer and fall through November in waters ranging from 400 – 1500 m in depth (Klepikovsky and Shestopal, 2006). Sightings in IMR surveys are relatively few, but according to previous catch records, northern bottlenose whales have a distribution similar to that of sperm whales, being concentrated south of the Barents Sea, with only large males migrating as far north as Spitsbergen. Sperm whales are regularly sighted in the Bleik Canyon area off Vesterålen, Norway, well south of the Barents Sea, and along the continental slope in the Norwegian Sea; but carcasses of large males do wash ashore annually in Svalbard (NPI fauna data base). Adult male sperm whales leave their natal pods and travel widely, first as part of male groups. They become more solitary with increasing age. Presumably adult males from the Vesterålen population are the ones that reach Spitsbergen (Christensen et al., 1992). IMR ecosystem survey indicates a stable distribution of individuals along the shelf edge.

4.3.7.13 Killer whales (*Orcinus orca*)

Killer whales occur in all world oceans and most seas, but their relative scarcity and sporadic occurrence make them difficult to census in the Barents Region. Photo-identification techniques have been used to recognise >400 individuals in northern Norway. Coastal killer whales are tightly linked to the availability of herring. During winter, killer whales aggregate in and around Vestfjorden in Lofoten, foraging on over-wintering herring. However, during that last few years herring have overwintered outside the fjords in the Norwegian Sea, which has greatly reduced coastal sightings in the Vesfjorden area. Surveys conducted in 1989 in the northern North Sea and eastern Norwegian Sea north to Bear Island suggest ~7,000 animals in this area. Killer whales have been sighted with increasing frequency in Svalbard waters in recent years, usually at the shelf edge, and in 2008 were observed as early as March at close to 80^{o} N (NPI Marine Mammal Sighting Data Base). Along the coast of Norway, several cases of killer whale predation on harbour and grey seals have been reported in recent years. There are also recent reports of killer whales feeding on harp seal pups in the West Ice area (Foote et al., 2013). Genetic analyses suggest that these mammal-eating killer whales belong to populations that were thought to be strictly piscivorous. This may suggest a shift in killer whale feeding patterns that may have significant effects on seal populations in the Northeast Atlantic.

4.3.7.14 Minke whale (*Balaenoptera acutorostrata*)

Among the baleen whales that frequent the Barents Sea on a seasonal basis, the minke whale is the most numerous. Recent estimates suggest that the population is quite stable (Solvang et al., 2015), although minor variations do occur in both distribution and point estimates. The most recent point estimate for minke whale abundance in the total area is numerically lower than previous estimates, but not significantly different from estimates based on the two preceding survey periods. The Small Management Area CM (the Jan Mayen area, part of the C region) has a current count that is only 40 % of estimates for the periods 1996-2001 and 2002-2007. This may have some unrevealed connection to the recent observed drop in minke whale abundance in coastal waters of Iceland. Within the E region, the point estimate was a bit higher than during the previous two cycles. There are general signs of a north- and eastwards distributional shift from the Norwegian Sea toward the Svalbard area and the Barents Sea. Distribution and migration patterns of north-east Atlantic minke whale are relatively poorly known, but in summer they are nearly ubiquitous in the Barents Region (Skern-Mauritzen et al., 2008). They can be seen around Spitsbergen with regularity from late spring until early autumn, particularly along the west and north coasts, usually as solitary individuals. They are also observed from May until September in the northern parts of the

White Sea and southern parts of the Barents Sea and in summer can be found as far west as the Kara Sea (pers. comm. Vladimir Svetochev). The exact proportion of the stock that utilises the Barents Sea is not known, but it is thought that regional prey abundance during any given year may be a strong determinant (Eriksen, 2006).

4.3.7.15 Fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*)

Fin whales and humpback whales are the second and third most abundant baleen whales in the Barents Sea, respectively. Both are fast-swimming, migratory species that over-winter in the south and occupy the Barents Sea during the productive summer months. The summer activity of these whales is dominated by feeding and during most of the winter; they are thought to fast while they are breeding. In the Barents Sea, fin whales generally inhabit deeper areas along the continental slope, west of Spitsbergen and in Storfjorden trough; in recent years, they have also been observed in the central and northern Barents Sea (Skern-Mauritzen et al., 2008). Humpback whales are highly migratory and are found in all the world's oceans. Although heavily depleted by earlier commercial whaling, they have shown strong recoveries both in the Pacific and Atlantic Oceans. The North Atlantic stock is believed to have increased considerably in the past 10-15 years. In the Barents Sea their distribution is generally north of the Polar Front in the western and central regions. They are regularly sighted around Svalbard as far north as Lågøya northeast of Spitsbergen (NPI Marine Mammal Sighting Data Base). Recently, they have also been seen with increasing frequency deep into fjords on Svalbard from early summer until late fall (Kovacs and Lydersen, personal observations, NPI Marine Mammal Sighting Data Base). The current situation, with a high Atlantic cod abundance and reduced capelin abundance, may impact the whales (and seals – see above) negatively through resource competition (Bogstad et al., 2015).

4.3.7.16 Blue whales (*Balaenoptera musculus*)

Blue whales are also summer residents in the Barents Sea. They probably number 600-1,500 individuals in the North Atlantic. In recent years, this species has been sighted frequently in Svalbard waters, up the west coast at the shelf edge as well as north of Spitsbergen. Similar to the fin whale, it also enters deeply into Svalbard fjords. It is sighted from early summer until late fall, and appears to be extending is seasonal presence in the northern Barents Sea (NPI Marine Mammal Sighting Data Base).

4.3.7.17 Bottlenose dolphins (*Tursiops truncatus*), Common dolphins (*Delphinus delphis*), White-sided dolphins (*Lagenorhynchus acutus*) and White-beaked dolphins (*Lagenorhynchus albirostris*)

Small cetaceans that frequent the Barents Sea include bottlenose dolphins, common dolphins, white-sided dolphins and white-beaked dolphins. All but the latter occur in the southern Barents Sea, particularly along the shelf break and over oceanic banks and ridges, but must be considered vagrants in the region. White-beaked dolphins are the only small cetacean species that routinely occupies the region more broadly.

White-beaked dolphin**s** dominate in terms of abundance, among dolphin species, throughout the Barents Sea, and are the most frequently observed small cetacean on joint Russian-Norwegian ecosystem surveys of the Barents Sea. During the period 2003-2007, these dolphins were mainly observed in southern and central areas of the Barents Sea in association with large schools of blue whiting (*Micromesistius poutassou*). More recently, the distribution of this species has shifted northwards and they are now often observed in association with capelin (Fall and Skern-Mauritzen, 2014). Declining abundance of blue whiting, and the northward shift in distribution of alternative prey species such as capelin, has likely contributed to the change in distribution of white beaked dolphins.

Along with declining sea ice coverage and warmer temperatures in coming decades, increases are expected in the productivity of the pelagic community in the Barents Sea; it is likely that this will result in increased abundances of migratory cetaceans in the area and longer periods of seasonal residence. The summer distribution of these animals is largely determined by prey availability. The increasingly long seasonal presence of migratory whales in the High North will likely increase competitive overlap between migrants and endemic Arctic marine mammal species (Kovacs et al., 2011a; Meier et al., 2014).

4.3.8 Seabirds

H. Strøm (NPI), J.V. Krasnov (MMBI). S. Descamps (NPI), M.V. Gavrilo (AARI), P. Fauchald (NINA), G.H. Systad (NINA), and G. Tertitski (RAS)

Numbers of seabirds breeding in the Barents Sea Region have changed dramatically over the last 50 years. A recent assessment of population status and trends has been conducted, based on monitoring and census date for several species breeding in the western part of the Barents Sea (i.e., Norwegian mainland and Svalbard) (Fauchald et al., 2015). Resulting analyses indicate that breeding populations of subarctic pelagic auk species (common guillemot *Uria aalge*, razorbill *Alca torda*, and Atlantic puffin *Fratercula arctica*) have increased in the southern colonies over the last 25 years. Most notably, the population of common guillemots breeding on the Norwegian mainland and Bjørnøya has recovered steadily since the mass mortality in the winter 1986/87.

Meanwhile, the large population of the Arctic sister species, the Brünnich's guillemots breeding on Spitsbergen have declined from about 1.15 million pairs in 1988 to about 520,000 pairs in 2013. The kitiwake population has also shown a steep decline, especially on the Norwegian mainland where the population decreased from approximately 170,000 pairs in 1988 to 40,000 pairs in 2013. The large gull species, herring gull (*Larus argentatus*) and black-backed gull (*Larus marinus*) are also declining in the southern Barents Sea. Similarly, the glaucous gull (*Larus hyperboreus*) has been declining on Bjørnøya; albeit, the status of this species on Spitsbergen is largely unknown. Trends for large populations of northern fulmar and little auks on Svalbard are also largely unknown.

The status and trends of breeding populations in the eastern Barents Sea is hard to assess due to a lack of long-term monitoring data. However, results from monitoring conducted by

MMBI in breeding colonies at Cape Gorodetski, Cape Krutik, and Dvorovaya Bay on the Kola coast (Figure 4.3.58) indicate contrasting trends for the common guillemot breeding population. The decline in the Brünnich's guillemot population documented in Svalbard and mainland Norway is evident along the Kola Peninsula. The population of kittiwake along the Kola coast seems to follow the same trend as on the Norwegian mainland, although not so dramatic as for many of the Norwegian colonies. Virtually nothing is known about the status and trends of the huge breeding populations on Novaya Zemlya and Franz Josef Land. In the White Sea, herring gull, lesser black-backed gull, and great cormorant are monitored annually on the Solovetsky Islands in Onega Bay. While the populations of great cormorant and herring gull have been relatively stable over the period 1991-2014, the lesser black-backed gull population has increased during the same period (Figure 4.3.58).

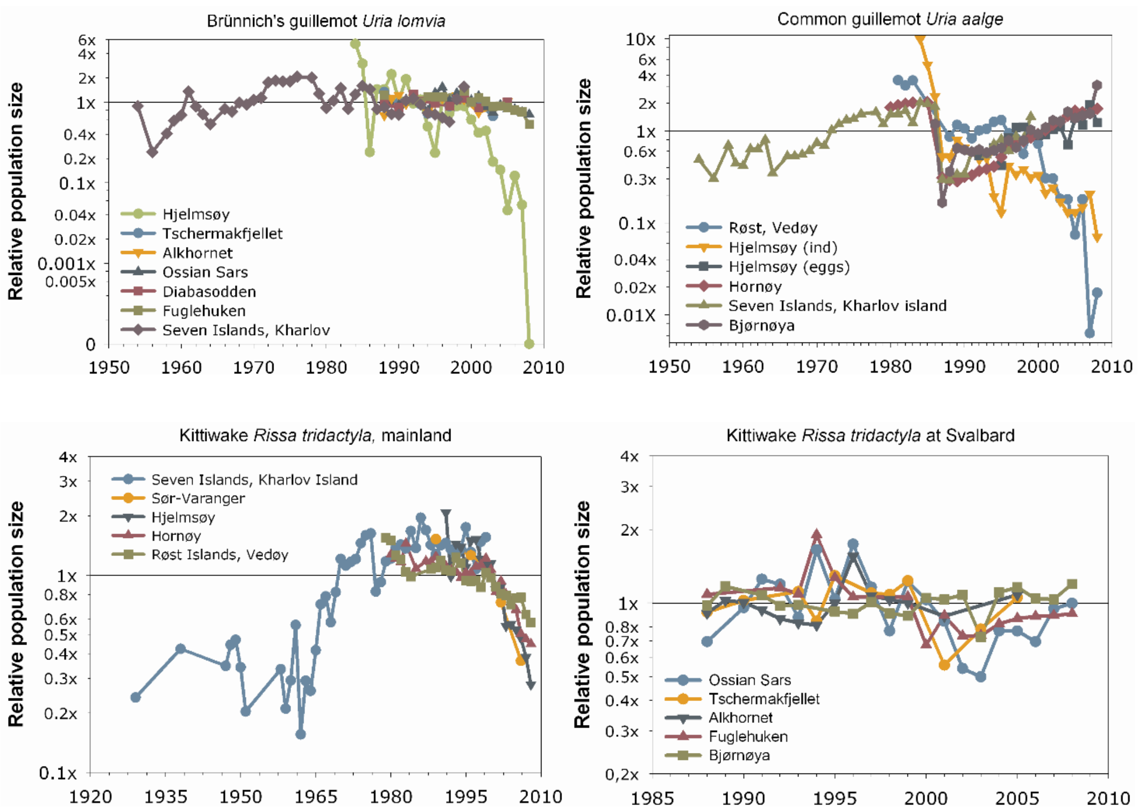
Reasons behind the recent changes in Barents Sea seabird communities are unknown, however several studies suggest that changes in food availability, often triggered by changes in ocean climate, govern population dynamics in species such as the common guillemot (Erikstad et al., 2013; Myksvoll et al., 2013), Brünnich's guillemot (Descamps et al., 2013), and kittiwake (Sandvik et al., 2014). In general, climatic variability in the Barents Sea is determined by the inflow of Atlantic Water masses, which again has significant effects on ice conditions and biological production, including movement and stock size of important seabird prey species, i.e., capelin, herring, and polar cod (Loeng, 1991). These large variations in the seabirds' preferred prey fish stocks have had consequences for some species, resulting in either serious declines in e.g., common guillemot, Brünnich's guillemot, and puffin breeding populations, or changes in chick diet composition and chick growth (Barrett, 2007). Direct effects of climate have also recently been put forth to explanation the decline in the common guillemot population in the Barents Sea (Mesquita et al., 2015).

In addition to climatic-induced variations in seabird populations, the fishing industry has also had large ecological impacts in recent decades through overfishing pelagic species which are seabird prey, and through fishing-induced shifts in predation pressure on these pelagic fish species (Gjøsæter, 1995).

For some seabird populations, changed patterns of predation from mammalian and avian predators might also be important factors. For example, an increased population of white-tailed eagle (*Haliaeetus albicilla*) might have increased predation pressure on some seabird species on the Norwegian mainland (Hipfner et al., 2012). As another example, changed ice-conditions in Spitsbergen fjords changed the polar foxes' (*Alopex lagopus*) access to islands with breeding colonies of common eider (Mehlum, 2012). For top predators and scavengers such as the glaucous gull, bio-accumulation of long-transport organochlorine pollutants has been shown an important contributing to population declines (Erikstad and Strøm, 2012). Finally, the present dynamics of several seabird populations on mainland Norway and Russia may still be influenced by the legacy of historic harvesting of eggs, chicks, and adults from breeding colonies (Krasnov and Barrett, 1995; Fauchald et al., 2011).

Two seabird species — great skua (*Stercorarius skua*) and northern gannet (*Morus bassanus*) — continue with both population increases and range expansions into the Barents Sea Region. Great skua has a very restricted breeding range, occurring only in the northeast Atlantic from northern parts of the British Isles to the Faroe Islands, Iceland, Norway, and Svalbard. Its numbers have been increasing since the beginning of the 20th century, and it has extended its breeding range progressively north and eastwards into the Barents Sea. Great skua was first recorded breeding on Bjørnøya in 1970 and on Spitsbergen in 1976. Since then the population has grown rapidly. Protection from human disturbance and improved food availability in key breeding areas in Shetland, Orkney, and Iceland are probably the main reasons for both increased population size and range expansion. In 2015, great skua had breeding sites throughout the Barents Sea Region, including the northernmost islands of Svalbard, Franz Josef Land, and Novaya Zemlya.

Northern gannet is a common North Atlantic species with its main centre of distribution in Britain. They began their colonisation of Norway in the mid-1940s at Runde, Møre, and Romsdal; they expanded into Northern Norway in the early 1960s, where the population increased in 1995 to ca. 2,200 pairs spread over five colonies (Barrett and Folkestad, 1996). Its breeding in Russia was observed for the first time in 1993, when three birds established themselves on Seven Island on the Murman coast (Krasnov and Barrett, 1995). Colonisation into the Barents Sea seems to be ongoing, as another small colony was recently established on Bjørnøya, Svalbard. The population in the Norwegian Sea has stabilised; fluctuating around 3,000 pairs annually since the early 1990s. However, the Barents Sea population continues to increase (Fauchald et al., 2015).



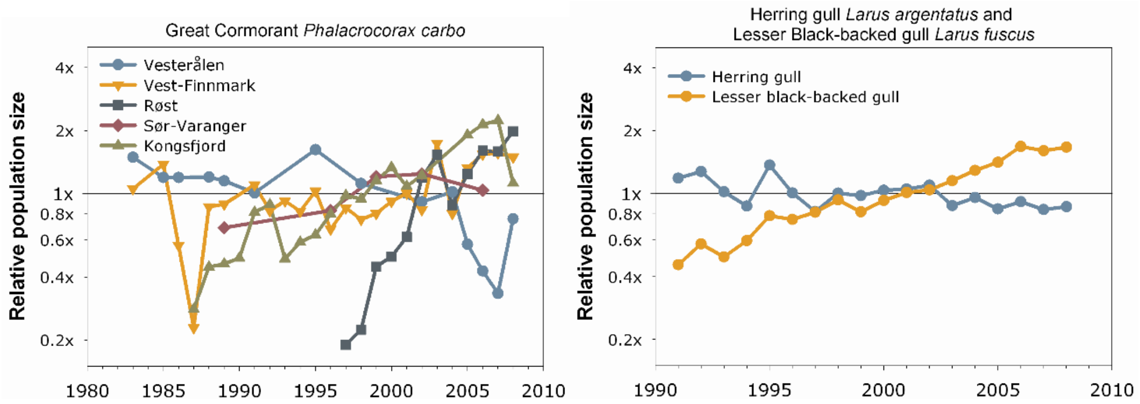


Figure 4.3.58. Trends in some seabird species monitored in the Barents Sea. Source: The Seabird Colony Registry of the Barents and White Seas and the Norwegian Institute for Nature Research.

4.3.9 Infectious organisms

V. Kuklin, (MMBI), M. Tryland (UiT - Arctic Univ. of Norway), and M.M. McBride (IMR)

Future higher temperatures in the Norwegian Arctic, including the Barents Sea, will likely cause several pathogens (parasites, bacteria, viruses) to extend their distributions northward (Tryland et al., 2009). The prevalence and abundance of pathogens may also change. Such a change in distribution of pathogens may have several consequences for both wild and domesticated animals, which are difficult to predict due to a lack of data. However, the following responses may be predicted with fair certainty:

- Cod farming is likely to become impossible along larger parts of the coast due to more northerly distribution of a highly pathogenic bacterium.
- Proliferative kidney disease, a disease which has been associated with severe declines in salmonid populations in Switzerland and England, will probably become more common.
- Abundance of certain nematodes in musk ox and reindeer will probably increase, resulting in more severe impacts.

Potential effects, that are harder to predict, include: invasions of new pathogens in a large number of animal host species; and changed abundance/prevalence of established pathogens. In addition to effects on single host species, this may also affect the overall dynamics of Barents Sea ecosystem (Tryland et al., 2009).

Specific research priorities to help predict impacts the of climate change on animal diseases suggested in the in the Arctic Climate Impact Assessment (ACIA, 2005), include:

1. Collection of baseline data on health parameters, as well as distribution, epidemiology and effects of pathogens and diseases in wild animal populations.
2. Studies that are focused on separating the effects of different climate variables on the dynamics of pathogens and disease in animals and humans (zoonoses).
3. Forecasting temporal and spatial effects of climate change on pathogen and host populations.

It will be important that scientific investigations take an inter-disciplinary approach benefiting from collaborations between ecologists and infectious diseases biologists. Investigations should focus on key host species and key pathogens within the Barents Sea ecosystem, and should include screenings and epidemiological studies (retrospective and real time), case studies, dynamic food-web modeling and experimental studies (ACIA, 2005).

4.3.10 Rare and threatened species

M. Tsyganova (VNIIPriroda), M. Gavrilo (AARI), I. Salvesen (ADB), S. Belikov (VNIIPriroda), J. Gjøsæter (IMR), K.M. Kovacs (NPI), J.A. Kålås (ADB), and H. Strøm (NPI)

4.3.10.1 Fish

The Barents Sea region is inhabited by 28 fish species which are either on the Global Red List (8 species) or on the Norwegian Red List (25 species) (Table 4.3.6). Among these, 13 are data deficient (DD) species, i.e. the species would likely appear on the red list if adequate information were available. When considering the lists of rare and threatened marine fish species, 3 main groups of impact factors may be considered: 1) fisheries (catch and by-catch); 2) environmental degradation (pollution, habitat destruction); and 3) effects of climatic change. Fisheries are believed to have the most important impact on red-listed species today; climatic changes may become equally or more important in the future, but less controllable (Table 4.3.6).

Among fish species on the Norwegian Red List which inhabit the actual area, 8 species are classified as threatened species (CR, EN, or VU). Of these, two species are classified as CR, critically endangered:

- ICES consider all spiny dogfish/spurdog (*Squalus acanthias*) in the entire area stretching from the Barents Sea to the Bay of Biscay to belong to the same population. Catch statistics show a steady and marked decline from 1973 (≈ 33,000 tonnes) to 2003 (5,000 tonnes). Due to late maturity and low fecundity this species is very vulnerable to overfishing.
- The other critically endangered species on the Norwegian red list is the European eel (*Anguilla anguilla*). This anadromous species is not considered further here due to its marginal importance in the Barents Sea.

Five species are classified as VU, vulnerable:

- Porbeagles (*Lamna nasus*) have a long life expectancy and low reproductive ability; this species is very vulnerable to overfishing. Reported catches have decreased from over 1,000 tonnes in the 1960s to about 20 tonnes in 2002. ICES recommends no fishing of this species; it is assumed that it will take at least 25 years to rebuild the stock even with minimal catch rates.
- Blue ling (*Molva dypterygia*) occur in the entire area and are fished commercially. Norwegian catches have been reduced from more than 2,000 tonnes in 1960 to less than 500 tonnes in 2004. Fisheries directed at blue ling have been stopped and it is only taken as a by-catch in the ling fishery. The closely related common ling (*Molva molva*) is listed

as near threatened (NT). After a severe decline in the past, this species now seem to be stabilizing or even increasing again in the northern part of its distribution area.

- *Sebastes marinus* and *Sebastes mentella* exists in the entire area and are fished commercially. Populations of both species have decreased considerably, probably due to overfishing. ICES considers both species to have reduced reproductive capacity; they therefore need protection to allow the stocks to rebuild.
- The lesser sand eel (*Ammodytes marinus*) is most important in the North Sea; they also occur along the coast of northern Norway and in the Barents Sea. This species is classified as VU on the red list mainly due to overfishing in the North Sea.
- Cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) are on the international red list, but neither species is considered threatened in the Barents Sea. The populations of coastal cod along the northern Norwegian coast is, however, rated as critical (CR) because of ongoing population reduction, poor recruitment and lack of effective regulation.

In addition to *Molva molva* mentioned above, *Hippoglossus hippoglossus, Somniosus microcephalus, Theragra finnmarchica,* and *Trisopterus esmarkii* are listed as near threatened (NT) on the Norwegian red list, and *Chimaera monstrosa* is listed as NT on the international red list. Among these species *Trisopterus esmarkii* and *Chimera monstrosa* are of minor importance in the Barents Sea.

The assessment of *Hippoglossus hippoglossus* as NT on the red list is based on trends in Norwegian catch statistics over the last 3 generations (45 years). North of 62°N the population has increased again during the last 10-year period; there recruitment seems to be good. Still halibut is considered threatened by overfishing due to its long reproduction period.

The once common Greenland shark (*Somniosus microcephalus*) population in the Northeast Atlantic is now very low; this species is rarely caught and registered. It is widespread in cold ocean waters in the northern hemisphere, but its biology is poorly understood. For reasons of its slow growth, late maturity, and low fecundity this species is listed as NT in Norway in accordance to the precautionary principle (IUCN, 2015).

Fewer than 60 individuals of Norway pollock (*Theragra finnmarchica*), which according to resent studies may be a substock of Alaska pollock (*T. Chalcogramma*), are known from 16 localities, all (with one exception) in the Norwegian sector, particularly outside the Tana fjord. All individuals have so far only been large specimens, most of them ready for spawning or having spawned.

Table 4.3.6. Species on the 2010 Norwegian Red List considered threatened due to negative population trends by category: critically endangered; endangered; or vulnerable. From Meld.St.10 (2010-2011) —Norwegian Ministry of the Environment (NMD, 2012).

Species(common name)	***Species (scientific name)***	***Category in the Red List***	***Abbreviation***
European eel	*Anguilla anguilla*	Critically endangered	CR
Blue skate	*Dipturus batis*	Critically endangered	CR
Spiny dogfish	*Squalus acanthias*	Critically endangered	CR

Basking shark	*Cetorhinus maximus*	Endangered	EN
Blue ling	*Molva dypterygia*	Endangered	EN
Golden redfish	*Sebastes marinus*	Endangered	EN
Porbeagle	*Lamna nasus*	Vulnerable	VU
Beaked redfish	*Sebastes mentella*	Vulnerable	VU
Common guillemot	Uria aalge	Critically endangered	CR
Black-legged kittiwake	*Rissa tridactyla*	Endangered	EN
Razorbill (Svalbard)	*Alca torda*	Endangered	EN
Razorbill (mainland Norway)	*Alca torda*	Vulnerable	VU
Black guillemot	*Cepphus grille*	Vulnerable	VU
Atlantic puffin	*Fratercula arctica*	Vulnerable	VU
Steller's eider	*Polysticta stelleri*	Vulnerable	VU
Common tern	*Sterna hirundo*	Vulnerable	VU
Brünnich's guillemot	*Uria lomvia*	Vulnerable	VU
Ivory gull (Svalbard)	*Pagophila eburnean*	Vulnerable	VU
Sabine's gull (Svalbard)	*Larus sabini*	Endangered	EN
Common guillemot (Svalbard)	*Uria aalge*	Vulnerable	VU
North Atlantic Right whale	*Eubalaena glacialis*	Regionally extinct	RE
Bowhead whale	*Balaena mysticetus*	Critically endangered	CR
Hooded seal	*Cystophora cristata)*	Endangered	EN
Narwhal	*Monodon monoceros*	Endangered	EN
Common seal	*Phoca vitulina*	Vulnerable	VU
Walrus (Svalbard)	*Odobenus rosmarus*	Vulnerable	VU
Common seal (Svalbard)	*Phoca vitulina*	Vulnerable	VU
Polar bear (Svalbard)	*Ursus maritimus*	Vulnerable	VU

4.3.10.2 Marine mammals

The Barents Sea is inhabited by 21 species of sea mammals. Among these, 11 species are threatened according to the IUCN Red List, 13 are included in the Red Book of the Russian Federation (2001) and 8 extant species are on the endangered species list of Norway (Table 4.3.6) (plus the recently extinct northern right whale stock). Anthropogenic factors thought to be most harmful for marine mammals are fisheries interactions, pollution, and climate warming; the latter is a particularly acute problem in the Arctic, and a serious threat for all ice-associated marine mammals. Increasing levels of tourism in Svalbard might also pose additional risk to polar bears in that region. Polar bears were severely overharvested in the Barents Sea Region, but became protected in 1973. The first population survey, in 2004, estimated that 2,650 bears reside in the northern Barents Sea; current population trends are unknown.

Walruses were dramatically overharvested in Svalbard during the 1800s and early 1900s; only a few hundred animals remained when they became protected in 1952. Walrus populations were also depressed by hunting in southern parts of the Barents Sea, extirpating them from the Norwegian mainland and reducing them throughout the Pechora and Kara Seas. Numbers of walruses in the Barents Sea have definitely trended positively in recent decades, though the rate of increase cannot be accurately assessed due to insufficient data. Walruses in the southern areas of the Russian zone are also thought to be increasing. Total population size of the entire northern Barents Sea is unknown; Russian areas have never been surveyed.

Little is known about narwhals in the Barents Sea. They do enter fjords north of Svalbard in summer and can be seen at the southern edge polar ice across the northern Barents Sea during summer, being most numerous near Franz Josef Land (Gjertz, 1991; Gorbunov and Belikov, 2008; NPI Marine Mammal Sighting Data Base).There is no abundance estimate for narwhals in the Barents Sea. They are believed to be less numerous than white whales in this area.

Extreme overharvesting in the Barents Region during the 1600s-1700s came close to exterminating the Spitsbergen stock of bowhead whales. The present number of bowheads belonging to the Svalbard stock is not known, but is presumably only in the tens (Christensen et al., 1992) or at most, in the low hundreds.

White-beaked dolphins are the only dolphin to remain in the Barents Region on a year-round basis. They are the most numerous dolphin species in the Barents Sea, with a population size of 60,000-70,000 individuals. The abundance trend for this species within the Barents Sea is not known.

Grey seals occur along the north coast of mainland Norway, east to about Murmansk. They have been heavily harvested in the past, being reduced to just 2 breeding locals and very low numbers in the 1950s in northern regions, with some 500-600 animals in Lofoten (Øynes, 1964). Hunting at breeding colonies was prohibited in Norway in 1973. Only 200 pups were produced in Troms and Finnmark in 2003 (Nilssen and Haug, 2007). Despite low numbers of grey seals, hunting bounties were instituted in 2003 to reduce numbers further. Grey seals were Red Listed in Russia in 1975 and have remained protected since then.

Harbour porpoises live year-round in the southern Barents Sea and in fjords along the coast of Norway. The Barents Sea population is believed to consist of about ~11 000 individuals (Bjørge and Øien, 1995). They are caught accidentally in coastal gillnet fisheries to an extent that may be unsustainable locally (Bjørge & Godøy, 2009); however, the population structure of porpoises in the Barents Sea and Northern Norway is not well described.

The northern bottlenose whale has a distribution similar to that of the sperm whale; being concentrated south of the Barents Sea, with only large males migrating as far north as Spitsbergen. There is no recent information about the distribution of this species in the Barents Sea. Fin whales and humpback whales are the second and third most abundant baleen whales in the Barents Sea, respectively. Although heavily depleted by earlier commercial whaling, they have shown strong recoveries both in the Pacific and Atlantic Oceans. The North Atlantic stock is thought to have increased considerably during the past 10-15 years. Blue whales are also seen in the Barents Sea, but they are so rarely spotted during sighting surveys of the region that a meaningful population estimate cannot be given for this species.

Other small cetaceans that frequent the Barents Sea include bottlenose dolphins, common dolphins and white-sided dolphins, all of which can be seen in the southern Barents Sea. Assessment of the population size of these small cetaceans in this region is complicated by the fact that dolphins are often difficult to identify; and tend to be grouped into “springers” during sighting efforts.

Most species of marine mammals in the Barents Sea region are currently protected. There is, however, a risk to small coastal seal populations the south because of policies aimed to reduce these populations to avoid conflicts with inshore fisheries and aquaculture. Cruise-ship tourism, which is particularly intense in Svalbard, poses potential risks to marine mammal populations; however little is known regarding its consequences. Industrial development including oil drilling and transport as well as other types of shipping pose risks to some marine mammals, particularly near the coast.

On a broader scale, regional pollution and projected climate change are perhaps the most serious threats to marine mammals in the Barents Sea. Although the Barents Sea is by no means heavily polluted, some animals living there (e.g. polar bears) exhibit high concentration of certain contaminants, in particular persistent organic substances such as polychlorinated biphenyls (PCBs).

Other ecosystem changes that can affect marine mammals include changes in food webs. The winter/spring harp seal invasions to coastal areas of northern Norway — resulting from shortages of capelin, polar cod, and herring — serve as useful examples. In addition to consuming fish, migrating seals may cause substantial damage to gill-net catches and the nets themselves. They probably also cause emigration of commercial fish species from traditional fishing grounds to deeper waters which are much less suitable for fishing. From the perspective of the seals, reduced recruitment prevailed during most of the seal invasion period.

The impacts of proposed climate change scenarios on marine mammals in Arctic regions are likely to be profound for endemic species. If increases in temperature and retraction of ice continue as predicted by many models, and suggested by current data trends, marine ecosystems would be expected to shift polewards; if the loss of sea ice is as dramatic as expected, profound negative consequences could ensue for Arctic animals that depend on sea ice as their breeding or foraging habitat. The predicted worst-case reductions in sea-ice extent, duration, thickness, and concentration from now until 2020, threaten the existence of whole mammal populations and, depending on their adaptability, could result in extinctions of some species.

Physical changes in the marine environment are likely to have impacts first and foremost on the animals that depend on sea-ice habitats. Any alteration to the distribution of sea ice and its characteristics will affect polar bears. To a large extent, the impact will be mediated via effects the physical changes will have on ringed seals and other ice-associated seals, which are the primary prey of polar bears. But, polar bears also need the ice directly as a corridor to move from one area to another. Reduced ice cover, particularly in the early spring and delayed formation in the autumn could have very negative long-term consequences for polar bears. For example, pregnant females build their birth dens in thick snow on land or on sea ice in some areas, and require good spring ice conditions when they emerge with their cubs after many months without eating. And, should the sea ice vanish, the only option left to polar bears would be the terrestrial summer life-style of brown bears (from which they evolved). Increased levels of human interaction would probably put this species' survival at risk.

Like the polar bears, ice-living seals are highly dependent on the nature and extent of sea ice, whether for pupping, moulting, or resting; some species also forage on ice fauna.

Walruses have specific ice requirements. If the ice extent in winter is reduced in years to come, the polar pack might retract to water too deep for walruses. Additionally, crowded haul outs that favour epizootic conditions, and local pressure on food resources, pose additional risks for walruses unable to utilize their normal rotation of ice and land. A further concern for walruses is that a decline in sympagic ice flora and fauna could result in a decrease in the flux of carbon to benthic communities upon which walruses are dependent. The species do haul out on land during summer in some areas and might therefore adjust more readily to land breeding than the other ice-breeding Arctic pinnipeds. This could however restrict their distribution quite dramatically — to areas where high-productive benthic communities are located close to suitable haul-out areas during ice-free months.

Hooded seals and harp seal suffer high pup mortality in years with little sea ice. It is impossible to predict whether harp and hooded seals will adjust to new locations for breeding and moulting if the spring-ice distribution changes dramatically over a relatively short time frame. The current situation for West Ice hooded seals — with declines of 85-90% in recent decades, in addition to 50% declines in White Sea harp seal pup production — does not bode well for flexibility in adjusting to changing conditions.

Harbour seals and grey seals are land breeders in the Barents Region. Sea ice actually limits the distribution of harbour seals, though grey seals use this habitat readily for breeding in other parts of their range. For these species, most climate change impacts are likely to be mediated through changes in their prey populations and via human interventions. Harbour seals in Svalbard are heavily dependent on polar cod, similar to ringed seals, so it is likely they will be required to shift prey. Productivity is likely to be higher overall in the Barents Sea with less ice and warmer temperatures, but it is difficult to predict what will happen to the intricate linkages throughout the region's foodweb. However, coastal population sizes of these two species in the Barents Region are currently largely determined by management decisions regarding hunting and culling levels within Norwegian territories.

The response of whales to climate-induced change is uncertain, but climate change is likely to have negative implications for species which are endemic to the High Arctic. The uncertainty of cetacean responses is linked primarily to uncertainty in future prey availability, in combination with our current lack of understanding of their linkages with sea ice. At very least the ice-associated cetaceans would be likely to face increased competition from migratory species in a warmer Arctic.

Bowhead whales are the most ice-adapted cetaceans, having evolved as ice-whales. Their low numerical status in the Barents Sea makes them particularly vulnerable. They are dependent on calanoid copepods and euphausiids for food; changes in sea-ice conditions are likely to have large impacts on their foraging. It is not known whether this species could survive in ice-free waters. Currently, narwhal and beluga also spend much of their time in association with sea ice, and are known to forage at the ice edge and in ice cracks. But, these two species also live far south of the ice edge in summer. Narwhal are thought to feed on cephalopods at this time of the year, so the impact of climate change on this species is likely to be mediated through changes in the distribution of sea ice and its effect on key prey species.

Other cetaceans which regularly frequent Svalbard waters avoid ice-covered areas. Pilot whales, white-beaked dolphins, northern bottle-nosed whales, fin whales, humpback whales, and blue whales all feed in open water areas and cover a wide range; their distribution is predominantly determined by prey availability. The impact of climate change on these species will likely also occur via changes to their prey base. If Arctic marine productivity increases as the seasonal ice cover diminishes, which is likely, it can be expected that more cetacean species will spread northward from temperate waters toward Svalbard and the northern Barents Sea.

Other threats posed by climate change to Arctic marine mammals include: increased risk of disease in a warmer climate; potential for increased pollution in the Barents Sea as a consequence of more precipitation and river-borne pollution; increased competition from temperate species that expand northward; stronger impacts of shipping along the Northeast Passage; and development (particularly petroleum development) in previously inaccessible areas. Complexities arising from alterations to the density, distribution, or abundance of keystone species such as polar bears could have significant and rapid consequences for the structure of the ecosystems they currently occupy.

4.3.10.3 Seabirds

Several seabird populations in the Barents Sea region are of international importance. The most numerous species are: Brünnich´s guillemot (*Uria lomvia*); little auk (*Alle alle*); Atlantic puffin (*Fratercula arctica*); black-legged kittiwake (*Rissa tridactyla*), northern fulmar (*Fulmarus glacialis*); and common eider (*Somateria mollissima*). An important part of the global breeding population of the rare ivory gull (*Pagophila eburnea*) is found within the northern part of the region — in Svalbard and Franz Josef Land.

Among the more than 30 seabird species breeding and wintering in the Barents Sea region are seven Red-listed species, including: two from the global list (IUCN, 2015); six from Norwegian Red List (Table 4.3.6); and three from the Red Data Book of the Russian

Federation. Four other species of concern are listed in the Annex to the Red Data Book of the Russian Federation. The only species listed in all three categories of the Russian Red lists is the ivory gull. Major threats limiting population development of Red-listed seabird species are: fisheries (competition for the resources and by-catch in gill-nets); environmental deterioration (pollution, habitat destruction, and disturbance); and climate change (Anker-Nilssen et al., 2000). Fishing is the major factor currently affecting half of the Red-listed seabird species; followed by environmental pollution — especially, oil pollution as a potential threat. While climate change will likely become more important in the future, currently it is only considered important for the ivory gull. Since seabirds are migratory species, causes of their unfavourable population status may lay beyond boundaries of the Barents Sea region.

The Steller's eider (*Polysticta stelleri*) is classified as globally threatened, and thus is a species of global conservation concern (Tucker and Heath, 1994). It is listed as vulnerable by the International Union for Conservation of Nature (IUCN, 2015). Significant numbers of this rare and declining seaduck winter along the coast of Finnmark and the Kola Peninsula (Anker-Nilssen, 2000; Systad and Bustnes, 1999; Krasnov, 2004; Zydelis et al., 2006). The population in the Barents Sea region is mainly a wintering population, but recent satellite tracking indicate that the species may breed on the west coast of Novaya Zemlya. Important moulting and staging areas are on the west coast of Vaigach Island, Novaya Zemlya, and the Murman coast (Krasnov et al., 2007; Petersen et al., 2006). Recent data indicate that the King Eider (*Somateria spectabilis*) may be decreasing in Norwegian wintering areas (Systad unpublished data); status of this species is uncertain, and needs to be followed closely.

The ivory gull breeds sporadically in Arctic archipelagos (ca. 25% of the world population); Greenland seabirds migrate through the area. The population trend over the last 15 years in the Russian part of the Barents Sea (Franz Josef Land and Victoria Island) is uncertain in general, but believed to be fluctuating or decreasing. Ivory gulls depend on the ice habitat and sympagic invertebrates and fishes throughout the entire annual cycle. Ice habitats in the northern portion of the Barents Sea recently vary considerably: with the area of summer ice cover decreasing; and the ice edge retreating to the north. This is believed to be the major reason for the abandonment of the breeding colony on Victoria Island. In other part of the breeding grounds, the population is likely to fluctuate in numbers and alternate its distribution patterns. This species is found to have high mercury (Hg) contaminant loads, and very high loads of dichlorodiphenyldichloroethylene (DDE) and polychlorinated biphenyls (PCBs). Data on reproduction parameters, food availability, and migration patterns dynamics are currently unavailable. Population numbers, local breeding distribution, food availability, and reproduction parameters are all expected to fluctuate in the future in response to local ice and snow conditions.

The white-billed diver (*Gavia adamsii*) is red-listed in Russia, and breeds sporadically in single pairs within the Russian zone. Most of the East Atlantic Flyway population winter in coastal waters off Norway, and some in Russia (off Kola Peninsula). No data is available on population trends, habitat dynamics, or key biological parameters. No reliable data are available to establish any future projection for the breeding period, but some data exists on the wintering distribution in Norway (www.seapop.no).

European shag (*Phalacrocorax aristotelis*) is red-listed in Russia as a rare species. Areas along the Murman coast form the only Russian breeding grounds, and represent the easternmost border of the species range. The population is estimated at 350-400 breeding pairs (b.p.). During 1930-1980, both a positive population trend and an expansion of breeding range were observed. In recent years, decade a slightly decreasing population trend has been observed at the easternmost part of East Murman. Food availability varies between years and affects local distribution of breeding birds, breeding performance, and reproductive success.

In Norway, the mainland population of the common guillemot (*Uria aalge*) is listed as critically endangered (CR). Black-legged kittiwake, common tern (*Sterna hirundo*), and Atlantic puffin are all listed as vulnerable ((VU) Kålås et al., 2006). In Svalbard the ivory gull (*Pagophila eburnea*) is listed as endangered (EN), and the common guillemot is listed as vulnerable (Kålås et al., 2006). No other seabirds are listed in the three top categories (CR, EN, and VU) in either Norway (including Svalbard) or Russia (Kålås et al., 2006). In Norway, several seabird species are listed in the two lower categories of the red list; near threatened (NT) and data deficient (DD) (Table 2.4.7).

Species for which Norway has a special responsibility — with a minimum of 25% of the European population either breeding or wintering in Norway — include: three breeding populations of seabirds (great black-backed gull *Larus marinus*, black-legged kittiwake, and Atlantic puffin); and wintering populations of: great northern diver; great cormorant (*Phalacrocorax carbo*); European shag (*P. Aristotilis*); Steller's eider; king eider; and red-breasted merganser (*Mergus serrator*). All of these species/populations inhabit the Barents Sea region either yearround or during one or more seasons. Species for which Russia has special responsibility — with a minimum of 25% of the European population breeding or wintering in the Russian zone of the Barents Sea — include: breeding populations of ivory gull and king eider; and wintering populations of Steller's eider and (probably) king eider.

Several seabird populations in the Barents Sea region are of international importance. The most abundant species are the Brünnich´s guillemot (*Uria lomvia*), little auk (*Alle alle*), Atlantic puffin (*Fratercula arctica*), black-legged kittiwake (*Rissa tridactyla*), northern fulmar (*Fulmarus glacialis*), and common eider (*Somateria mollissima*). An important part of the global breeding population of the rare ivory gull (*Pagophila eburnea*) is found within the northern part of the region: at Svalbard and Franz Josef Land.

*A new edition of the Red Book of the Russian Federation (RF) is being prepared, where there will be some changes to the list and categories of some species, subspecies, and populations of animals. However, while the book is under preparation, this text is using the current Red Book of the RF (2001).

4.3.11 Introduced / non-indigenous species

M. Tsyganova (VNIIPriroda), B. Berenboim (PINRO), A. Jelmert (IMR), J. Gjøsæter (IMR), J.A. Kålås (ADB), and I. Salvesen (ADB)

In recent decades, non-indigenous species which may be considered both "introduced" and "invasive" have appeared in the Barents Sea. Currently, 15 of them have been identified. These organisms entered the Barents Sea either in a natural manner — through the expansion of habitat due to global warming — or as a result of human activities, related to the intentional or accidental introduction of non-indigenous species.

At present, studies related to the invasive species are mainly focused on two species of crabs: Red king crab (*Paralithodes camtschaticus*) and Snow crab (*Chionoecetes opilio*). Fisheries are conducted for these crab species; both are considered to be of economic importance. Scientific information regarding other invasive species is fragmentary and requires further research.

Below is an annotated list of species introduced into the Barents Sea; it provides additional details about the two species of crabs:

- *Codium fragile ssp. fragile* (a type of seaweed). The taxonomic resolution of the complex is uncertain. The subspecies regarded as the most invasive, *C. fragile ssp. tomentosoides,* currently has a more southerly distribution. It is regarded rather unlikely that C. fragile-species will have serious impacts on the Barents Sea Ecosystem.
- *Bonnemaisonia hamifera* (a marine alga) is found in the littoral and in littoral ponds along the coast. There is a limited knowledge on effects and spread. It is regarded rather unlikely that *B. Hamifera* will have serious impacts on the Barents Sea Ecosystem.
- *Caprella mutica* (Japanese skeleton shrimp) was first observed in W. Norway in 1999. Today observed along the coast around Tromsø. There is little knowledge on effects on ecosystem or indigenous species.
- *Heterosiphonia japonica* (red seaweed) is currently not found north of Trondheim. Has grown and spread fairly aggressively south and north of the place originally observed close to Bergen.
- *Molgula manhattensis* (marine invertebrate). This sea-squirt is currently found in southern Norway, not in the Barents Sea proper. Hard-bottom species.
- *Balanus improvisus* This barnacle has been established in Norwegian waters since first half of 20th century. May compete with indigenous barnacles for space and food. Limited knowledge on other effects and current northern range.

4.3.11.1 Red king crab (*Paralithodes camtschaticus*)

Red King crab was introduced deliberately to the Barents Sea in the 1960s by Soviet scientists, and the stock has increased heavily in abundance as well as in distribution. The crab is now common in coastal areas from Cape Kanin in the east to Northern Troms in the west. It is a highly valuable product on the market. The red king crab fishery in the Barents Sea started as an experimental fishery in 1994 with a quota of 11,000 crabs in both the

Norwegian and Russian zones. This quota increased during the 1990s to 100,000 in 2001. In 2002, the Norwegian king crab fishery became a commercial fishery with vessel-quotas, while the Russians introduced a licensed commercial fishery in 2004.

Despite agreements during 2005-2007 to establish common principles of management of a new biological resource, both Norway and Russia managed fisheries for the red king crab stock separately within their respective economical zone, and agreed to inform each other about the national measures taken. In Norway, the main research goals have been to reveal the effects of red king crab on the ecosystem and to prevent its further distribution in Norwegian waters. In Russia, however, the main focus is on rational harvesting of the stock. In Norway, the crab fishery is subjected to two different regimes. In a limited commercial area east of 26º East, the crab stock is harvested as a sustainable commercial species; while outside this area there is a non regulated free fishery aiming to prevent further spreading of the crab. In the Russian zone, fishery regulations are still based on principles agreed upon with the Norway. Thus, fisheries for the red king crab stock are subjected to three different management principles: 1) in Russian waters they are based on elements of the precautionary approach; 2) in open Norwegian waters and to the west of North Cape, there is an open fishery to prevent spreading; and 3) in the fjords of eastern Finnmark the fishery is aimed to maintain a low stock level.

4.3.11.1.1 Impact of red king crab on the Barents Sea ecosystem

The impact of red king crab on Barents Sea benthic fauna was a significant theme in two three-year Joint Russian-Norwegian research programs on this species during 2002-2004 and 2005-2007. This species was studied both in terms of its population expansion and its impact on benthic communities. Central topics were the effects of red king crab feeding activity on the benthos, and the interspecies relationships between the crab and other commercial species with emphasis on red king crab both as both a predator and as a competitor for available food resources.

Motovsky Bay in the southern Barents Sea was the main area for these studies. This area was chosen because red king crab has been abundant there since its introduction to the Barents Sea. In addition, published results from studies conducted — during 1931-1932 and 1996-2003 — on the benthos in this Bay were available. The king crab has inhabited this area for more than four decades, and appears to have successfully adapted to its new environment. The benthic community in this area is dominated by the sedentary polychaete *Maldane sarsi*.

Results indicate that red king crab has not had a significant impact on either indices of species abundance or species diversity for the benthic community in the deep-water of the Bay. The local variations in total biomass and the structure of the community recorded in the open part of the bay was probably due to fishing activities which was mainly carried out in the open north-eastern part of the Bay. It is believed that observed changes within benthic communities in this area were more likely caused by the fishing activities than by an abundant king crab stock feeding in the area.

The influence of the red king crab on the Iceland scallop stocks was studied by analyzing the stomach content of crabs in non-harvested parts of the scallop beds, and on scallop beds that were harvested. These investigations showed that crabs foraging on beds that were harvested consumed significantly more scallops than in areas where there were no scallop fishery going on. The observation of scallop fragments in the crab stomachs may indicate that, in harvested scallop beds the crabs primarily consume wastes of scallop from the fishery and specimens damaged by the dredge. In beds with no fishing the crabs feed exclusively on young scallops.
In the Varangerfjord, close to the Russian-Norwegian border, detailed studies of the benthic community had been done at two locations in 1994, just prior to the invasion of the red king crab. In 2008 the sites were revisited and large changes in the benthic communities were found. In one of the locations, the most striking observations were a total absence of the mud sea star (*Ctenodiscus crispatus*) and a significant reduction of brittle stars (Ophiuroidea). In 1994 *Ctenodiscus* was present in a density of 10-15 ind./m^2 here. In addition, several species of bristle worms and bivalves were reduced or absent. In the other location, it was observed a similar reduction or absence of large specimen of biologically important taxa. For example, no brittle stars of any species were observed in 2008, and very few specimens of the sea urchin (*Strongylocentrotus droebachiensis*) — which were common in 1994 — were observed in 2008. The bivalves *Mya truncata* and *Macoma calcarea* were highly reduced, and only some few larger specimens were found. It also appeared that smaller bivalve species was reduced or absent. Among the bristle worms, *Harmothoe imbricata*, which were abundant at the shallowest station (10m depth) in 1994, seemed to be totally absent in 2008. The same holds for *Nothria conchylega*, which were common at the two deepest stations in 1994 and not recorded in 2008. The authors of the study conclude that the observed changes are likely to be caused by feeding activities from the king crab (Oug and Sundet, 2008).

Feeding of the crab on fish eggs during spring has been documented. However, the long-term observations showed that, on the average, in spring, the frequency of occurrence of fish eggs in crab stomachs was less than 6% and the weight portion in the crab diet less than 2%. The highest frequency of occurrence of fish eggs (mainly capelin eggs) in crab stomachs were registered in 2001 (19.4%). Preliminary estimations indicate that in this particular year about 37 tonnes of capelin eggs were eaten by red king crabs in Western Murman waters. In the Russian Economic Zone, the capelin spawning stock accounts for the one third of the total spawning stock and was estimated to be 99.5 billion individuals in 2001. The weight of an egg clutch from one female capelin is on the average 8 gram. Thus, the total amount of eggs spawned by the capelin stock in 2001 in Russian waters is estimated to 130 thousand tonnes. The simple calculations therefore show that, in 2001, the red king crab ate about 0.03% of the weight of all capelin eggs spawned. It is therefore reasonable to believe that the king crab feeding on eggs does not influence the capelin spawning stock significantly.

Long-term studies indicate that the main food items for red king crabs in the Barents Sea — echinoderms, molluscs, and worms — are also major prey species for the haddock. Therefore, any food competition between the red king crab and haddock should result in lower frequency of occurrence in haddock stomachs. A comparative analysis of haddock stomach content during a period (1971-1977) of low red king crab abundance with a period of increased red king crab abundance (1995-2002) was conducted; this analysis did not indicate any direct food competition between these two species in the Russian part of the Barents Sea.

4.3.11.2 Snow crab (*Chionoecetes opilio*)

After snow crabs were first observed on Goose Bank in 1996, the number of reports on snow crab by-catches in bottom-trawl fisheries has gradually increased (Pavlov, 2002). Since 2003, the snow crab has been observed in stomachs of cod, haddock, catfish, and thorny skates. Thus, snow crabs have become a new food item for bottom fish in the Barents Sea. In 2005, the first snow crab was captured during the ecosystem survey. During 2005-2008, both the number of trawl stations where this species occurred and the number of individuals per station increased. During that period, the crab occurred in bottom trawl catches in most of the eastern Barents Sea — concentrated mainly in areas adjacent to Goose Bank and the southern extremity of Novaya Zemlya.

In 2007-2008, directed trawl surveys for snow crab were initiated; Goose Bank and adjacent areas in the eastern Barents Sea were surveyed. During these surveys, the highest snow crab abundance was 95 specimens per haul/hour. Males were predominated (84%) in the catch, and greatest density of crabs (145-320 ind./km^2) occurred south of Goose Bank.

Survey results indicate that the snow crab has adapted to the Barents Sea; it is assumed that its abundance will increase in the eastern Barents Sea in the near future. Due to this, it is expedient to monitor both distribution and abundance of this species regularly, and to evaluate its impact on the ecosystem.

4.4 Human activities /impact

4.4.1 Fisheries and other harvesting

K. Nedreaas (IMR), O. Smirnov (PINRO), and A.A. Russkikh (PINRO)

4.4.1.1 F ishing

Substantial removals make fishing the human activity that has the largest impact on fish stocks and functioning of the entire Barents Sea ecosystem. A fishery is not considered sustainable if it impairs recruitment potential of the stock. Single species management often focuses on measuring status of the fishery in relation to benchmarks called biological reference points (BRPs). BRPs for single species management are usually defined in terms of the fishing mortality rate (F) with target and limit reference points, and total- or spawning stock biomass (TSB or SSB). Limit BRPs suggest maximum levels of F and minimum levels of B that should not be exceeded. These BRPs are then compared to estimates of F and B from stock assessments to determine the status of the fishery and suggest management actions.

Fishery removals at the limit reference point for fishing mortality (F_{lim}) will eventually bring the spawning stock down to B_{lim}, below which recruitment will be impaired. Hence, F_{lim} may be used as an indicator for unsustainable exploitation representing a negative influence on both the stock and the ecosystem. Keeping F below F_{lim} and the stock above $B_{lim,}$ however, may not always be enough to ensure sustainable fisheries. Additional specific management actions may be required for each stock harvested.

In accordance with collective international guidelines, ICES aims to inform management decisions to ensure optimal yield from fisheries and maintain productive fish stocks within healthy marine ecosystems indefinitely. The concept of maximum sustainable yield (MSY) was recently implemented into the ICES framework, and MSY reference points have been identified and implemented into fishery management strategies for several stocks. As result, the fisheries advice provided by ICES integrates the precautionary approach, MSY, and an ecosystem approach under a single advisory framework.

Moreover, it is recognized that a fishery cannot be considered optimal if individual fish are harvested prematurely, i.e. if the net natural growth and production potential is not attained. This pattern is called "growth overfishing" and may result in a total yield that is less than it would be if individual fish were allowed to grow to an appropriate size. Introduction of minimum catch size and selective gears are the most common management measures to avoid growth overfishing. Similarly destructive patterns of fishery removals which should be avoided include: "recruitment overfishing" which occurs when spawning stock biomass is depleted to a level where it no longer has the reproductive capacity to replenish itself, i.e. there are not enough adults to produce offspring; and "ecosystem overfishing" which occurs when the balance of the ecosystem is altered by overfishing, e.g. declines in the abundance of large predatory species may lead to increases in abundance of small forage fish causing a shift in the balance of the ecosystem towards smaller fish species (Murawski, 2000).

The main demersal fish stocks harvested in the Barents Sea and adjacent waters (ICES areas I and II) are cod, haddock, and saithe. In addition, redfish, Greenland halibut, anglerfish, wolfish species, and flatfish species (e.g. long rough dab, plaice) are common on the shelf and at the continental slope; ling and tusk are found at the slope and in deeper waters. During 2013, approximately 1,385 thousand metric tons (total reported catch) were removed from stocks of cod, haddock, saithe, redfish, Greenland halibut, wolffish, and anglerfish. Total reported capelin catch during 2013 was 177,000 metric tons. Other species with relatively small landings include: salmon; Atlantic halibut; hake; pollack (*Pollachius pollachius*); whiting; Norway pout; lumpsucker; argentines; grenadiers; flatfish; dogfish; and skates.

The most commonly used gear in the Barents Sea is the bottom trawl, but longlines and gillnets are also used in demersal fisheries (Figure 4.4.1). Pelagic fisheries use purse seines and pelagic trawls. Other gears more common along the coast include hand-lines and Danish seines. Less frequently used gears are float-lines (used in a small directed fishery for haddock along the coast of Finnmark, Norway) and various pots and traps (used for fish and crabs). Types of gears used vary with species targeted, time/season, area, and country. A variety of gear types are used in Norway to conduct coastal fisheries. Fishers from Russia commonly use bottom trawls, but a longline fishery largely directed at cod and wolffish is also conducted. Other countries fishing in the Barents Sea typically use bottom trawls.

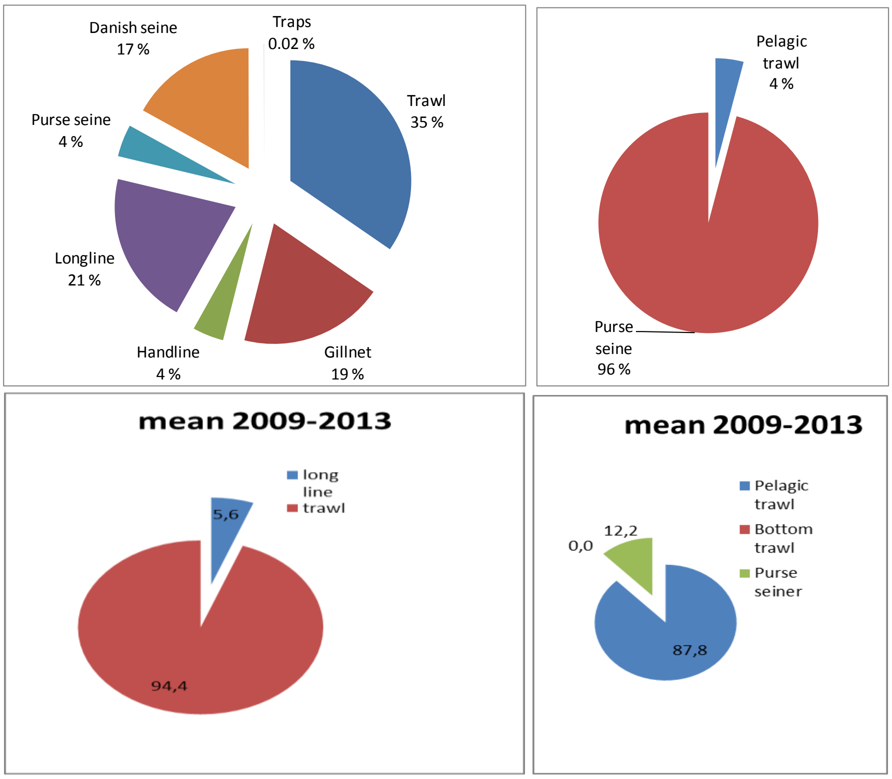


Figure 4.4.1. Upper panel – gears used in Norwegian groundfish (2012-2013; left) and pelagic capelin (2012-2013; right) fisheries in the Northeast Arctic (north of 67°N). Note that purse seine is solely used in the coastal groundfish fishery for saithe. Lower panel – gears used in Russian groundfish (2009-2013; left) and pelagic capelin (2009-2013; right) fisheries in the Northeast Arctic.

The Norwegian bottom trawl fleet accounts for about 30% of the Norwegian cod landings, about 40% of haddock landings, and more than 40% of Norwegian saithe and Greenland halibut landings. The Russian bottom trawl fleet accounts for about 100% of the Russian saithe landings about 95% of cod and haddock, 90% of the Russian Greenland halibut, and about 40% of wolffish landings. Other countries fishing groundfish in these waters use only trawls, including some pair-trawls.

For most exploited stocks, a total allowable catch (TAC) quota is agreed upon and a number of additional regulations are applied. Regulations differ among gear types and species targeted, and may vary between countries. Discarding is prohibited for fisheries conducted in the Barents Sea.

4.4.1.1.1 Northeast Arctic cod, haddock, and saithe

Annual landings of Northeast Arctic cod, haddock, and saithe for the Barents Sea are presented in Figures 4.3.38, 4.3.40 and 4.3.53 (Subchapter 4.3.6). The fishery for Northeast Arctic cod is conducted both by an international trawler fleet operating in offshore waters and by vessels using gillnets, longlines, handlines, and Danish seines operating in both offshore and coastal areas; 60-80% of annual landings are from trawlers. The regulated minimum landing size for cod is 44cm, and the maximum proportion of undersized fish allowed is 15% of the number of cod, haddock, and saithe combined. Fisheries are controlled by inspections at sea, required reporting at catch control points when entering and leaving the EEZ, and by fish landings inspections for all commercial vessels. During 2002-2006, the rate of fishing mortality (F) ranged from 0.50 to 0.70, but decreased to 0.35 in 2007, and has remained below 0.30 since then. This F level is below that intended under the agreed management plan (0.40), but is within the range associated with high long-term yield and low risk of decreased stock reproduction potential. For 2014, ICES advised a TAC of 993,000 metric tons as agreed in the management plan.

The haddock fishery is primarily conducted using trawl gear; haddock are also taken as bycatch in the cod fishery. In 2013, about 36% of the total haddock catch was taken using conventional gear types, primarily longlines. The fishery is regulated through: a minimum landing size (40cm), a minimum mesh size for trawls and Danish seines (130mm); a maximum bycatch of undersized fish (15% by number for cod, haddock, and saithe combined); closure of areas with high densities/catches of juveniles; and other seasonal and area restrictions. Historically, about half of the Russian haddock catch is taken within the Russian EEZ. In recent years, warming temperatures in the Barents Sea have influenced distribution of the haddock stock, and thereby have influenced conditions to conduct this fishery. Since 2003, value of the haddock catch in Spitsbergen has increased; during 2010-2012 it peaked, and total haddock catch exceeded that from other areas of the Barents Sea. In 2013, the geographical distribution of catches was more normal, and less than 1/3 was caught in the Spitsbergen (Svalbard) area.

Northeast Arctic saithe is mainly fished by Norway, accounting for more than 90% of total landings. Over the last ten years about 40% of the Norwegian catch has been taken using bottom trawls, 25% using purse seines, 20% using gill nets, and 15% using other conventional gears (longlines, Danish seines, and hand lines). The gill-net fishery is most intense during winter, purse seine during summer; while the trawl fishery takes place more evenly throughout the year.

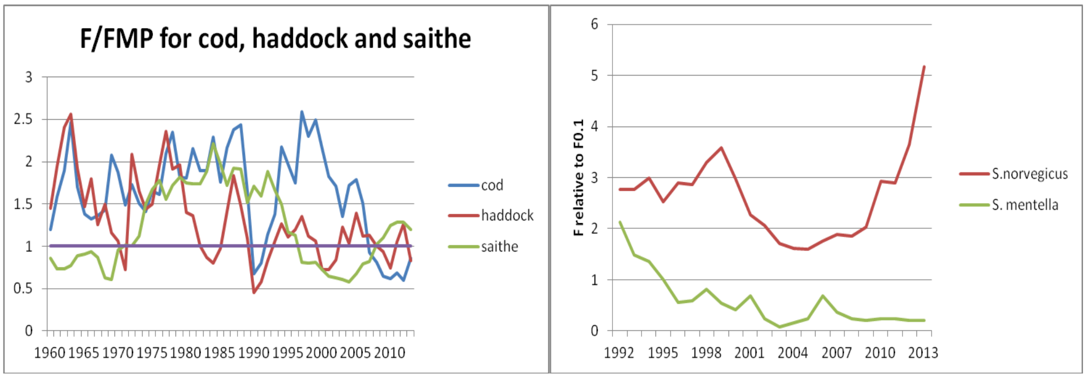


Figure 4.4.2. Left panel - annual fishing mortalities of the Northeast Arctic cod, haddock and saithe stocks relative to F_{MP}, i.e., the level used in the management plan for these stocks when SSB > B_{pa}. Right panel - annual fishing mortalities relative to $F_{0.1}$ for Golden redfish (*Sebastes norvegicus*) and Beaked redfish (*Sebastes mentella*).

Since 1985, exploitation rates have been critically high during some periods, particularly for cod; the rate was also very high for haddock before 1995 (Figure 4.4.2). Because of the harvest control rule and better enforcement, this problem seems reduced in recent years. The recent increased exploitation rate for saithe needs to be monitored carefully. Cod and haddock are mostly taken in mixed fisheries; optimal allowable catch for these species may be based not only on estimated F, but on ratios of these species comprising the catch. Although the exploitation rate may be too high to fully reach the stock production potential, it may be concluded that since 2000 exploitation of these three stocks has been sustainable, has not impaired recruitment, and has not impacted the ecosystem negatively.

4.4.1.1.2 Greenland halibut (*Reinhardtius hippoglossoides*)

Greenland halibut is mainly fished in directed trawl and longline fisheries in slope areas of the continental shelf. This species is also taken as bycatch in other groundfish fisheries across the Barents Sea (Figure 4.4.3). During 1992-2009, directed fisheries for Greenland halibut were banned in the Barents Sea. During the last 10 years, average annual landings have been around 17,000 metric tons (Figure 4.4.3). Given the condition of the stock and lack of available information, ICES has recommended that the fishery should not exceed 15,000 metric tons until better information is available, and firm evidence of a larger stock size has been obtained. Trawl gears typically catch larger percentages of young fish compared to gillnets and longlines. Nevertheless, 6–10 year-old fish continue to represent major age groups targeted in the fishery. Prior to decreased levels in the early 1990's, rates of fishing mortality had increased continuously for more than a decade and peaked in 1991
For Greenland halibut, no limit reference points have been suggested or adopted. The assessment is still considered uncertain due to problems with the age-reading and the quality of input data. The preliminary assessment may nevertheless be indicative of stock trends. Although many aspects of the assessment remain uncertain, fishery-independent indices of stock size from research surveys indicate a positive trend in recent years.

After many years of overexploitation, tentative indications are that the Greenland halibut stock is being harvested sustainably at the current rate of exploitation. Uncertainties remain, however, due to a lack of precision in the stock assessment.

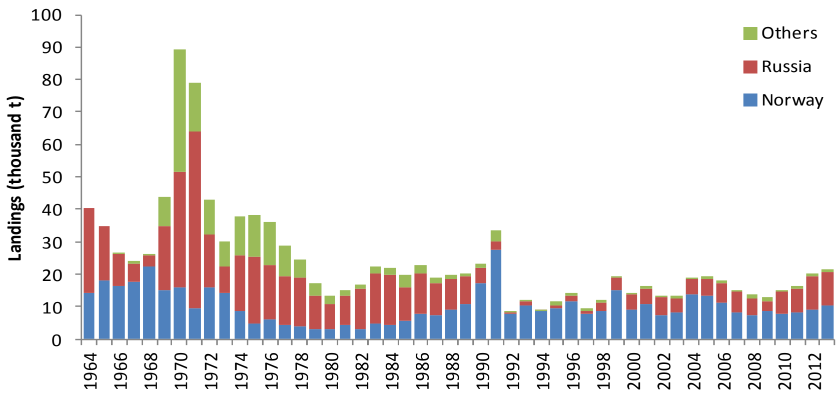


Figure 4.4.3. Northeast Arctic Greenland halibut landings (1964-2013).

4.4.1.1.3 Golden redfish (*Sebastes norvegicus*)

Annual landed catch of golden redfish in the Barents Sea was approximately 7,000 metric tons during 2004-2010, and decreased to approximately 5,500 metric tons during 2011-2013. No limit reference points have been suggested or adopted for this species. Estimated SSB has been decreasing since the 1990s, and is currently at the lowest level in the time-series. Estimates of fishing mortality have been increasing since 2005; the current F is the highest level in the time-series (Figure 4.4.2). Recruitment is very low. ICES has advised no fishing on this stock, given the very low SSB (below any possible reference points) and poor recruitment.

Management experiences with fisheries for *Sebastes* stocks in other, e.g., in the Pacific Ocean and the Irminger Sea, suggest that annual harvest rates for these slow-growing and long-lived species should not exceed 5% if the stock is recruiting normally. At times when the stock is not recruiting normally, even a rate of 5% may be too high. It can thus be concluded that the current fishery for golden redfish is too intensive. Using $F_{0.1}$ as a precautionary proxy for F_{msy}, fishing 1,400 metric tons per year ($F_{0.1}$=0.08) should produce sustainable yield at current levels of recruitment. A management plan is currently under developing in Norway.

4.4.1.1.4 Beaked redfish *(Sebastes mentella)*

The stock of beaked redfish in ICES Subareas I and II, also called the Norwegian-Barents Sea stock, is found in the northeast Arctic from 62ºN in the south to the Arctic ice north and east of Spitsbergen (Figure 4.4.2). The southern limit of its distribution is not well defined, but is believed to be somewhere on the slope northwest of Shetland; the abundance of this species decreases south of this latitude. Nonetheless, the 62ºN boundary defines the management unit more so than biological stock separation. The analytical assessment and management advice are provided for ICES Subareas I and II combined.

Fisheries for beaked redfish are conducted in both national and international waters of the Barents Sea under different management authorities using different management schemes. In international waters, a pelagic fishery for beaked redfish is managed by the North East Atlantic Fisheries Commission (NEAFC). In recent years, an Olympic fishery has been conducted with a set TAC that is not derived from a harvest control rule. In national waters of the Barents Sea, a demersal fishery based on bycatch is conducted with specific bycatch regulations. It is important that management decisions taken at national and international levels are coordinated to ensure that the total catch in ICES Subareas I and II does not exceed the recommended TAC.

Since 2004, a directed pelagic fishery for beaked redfish in international waters beyond the EEZ of countries bordering the Norwegian Sea has developed. In 2013, this fishery had a TAC of 19,500 metric tons, of which about 9,300 metric tons were landed. Otherwise, this species is taken: as bycatch in demersal fisheries for cod, haddock, and Greenland halibut; as juveniles in the shrimp trawl fisheries; and occasionally in pelagic fisheries for blue whiting and herring in the Norwegian Sea.

There have been several consecutive years (1998–2005) with very low recruitment of this long-lived, late-maturing species. This trend together with continued landings, suggests that SSB of beaked redfish may be expected to decline in the near future. The Joint Norwegian-Russian Fisheries Commission decided to avoid sharply increased quotas over the next years and to pursue a more precautionary approach. This is significant since implementation of a new analytical method may give rise to shortcomings. Because beaked redfish is a long-lived species, there should be no loss of long-term revenue by waiting for evidence of improved stock conditions before increasing the TAC. As with the management of many other long-lived species, and in keeping with responsible and precautionary strategies, TAC-increases should be made gradually, and not following a single year of perceived improvement.

At present, no fishing mortality or biological reference points have been determined for this stock. An $F_{0.1}$ value of 0.039 is considered a good proxy for F_{MSY} when the stock has been re-built. For 2014, ICES advised a status-quo TAC of 24,000 metric tons for beaked redfish, and that measures currently in place to protect juveniles should be maintained. Currently estimated fishing mortality is below the assumed natural mortality (0.05) and below the proxy for F_{MSY} ($F_{0.1}$=0.039) (see Figure 4.4.2). Fishing at $F_{0.1}$, which is close to the assumed value of natural mortality is not considered to be detrimental to the stock.

ICES has evaluated a variety of proposed management strategies for the beaked redfish stock and identified a number of options that are considered precautionary and consistent with the MSY approach. They conclude that the following elements should be incorporated in a future management plan:

- A biomass trigger of 600,000 metric tons is a good starting point for management.
- There is little long-term gain in yield if F_{target} is increased above 0.039.
- The stock and recruitment might benefit from delayed or gradual implementation of a management plan, or a gradual increase of F (fishing at F_{target} only after stronger incoming year classes have fully recruited to the fishery in 2017/2018). A low fixed TAC in the initial period or a stabilizing element in the management plan might have a similar effect if implemented on the basis of recent catches.

Based in these precautionary considerations, ICES advised that annual catch in 2015, 2016, and 2017 be set at no more than 30,000 metric tons, and that measures currently in place to protect juveniles should be maintained.

4.4.1.1.5 Wolffish (*Anarhichas spp.*)

Three species of wolffish: Atlantic wolffish (*Anarhichas lupus*); spotted wolffish (*Anarhichas minor*); and northern wolffish (*Anarhichas denticulatus*) are taken mostly as bycatch in fisheries for gadoids in the Barents Sea. Although wolffish are sometimes the dominant catch in longline fisheries, total catch of these species is relatively small (Figure 4.4.4).

Northern and spotted wolffish comprise more than 90% of the total catch. Atlantic wolfish are caught in the coastal zone.

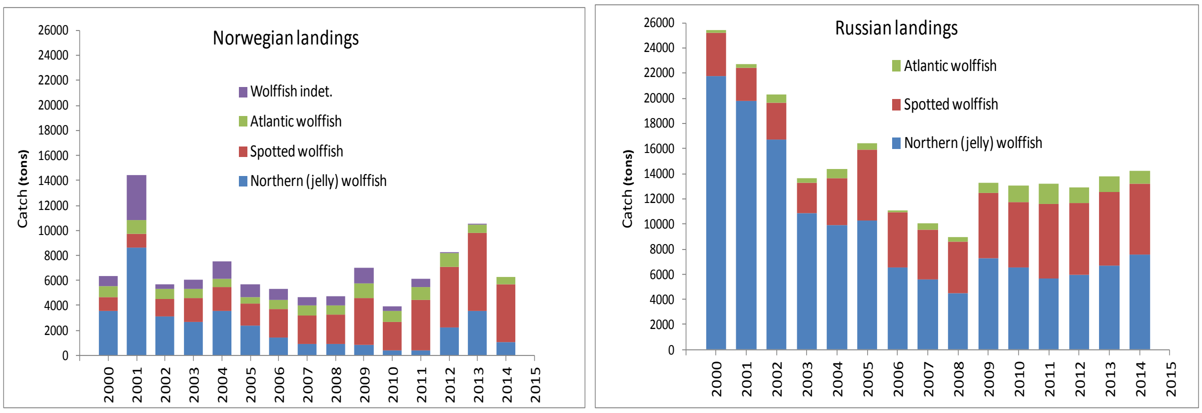


Figure 4.4.4. Annual landings of wolfish/ catfish by the Norwegian (left) and Russian fleet (right) during 2000-2014 (Grekov 2014, IMR 2014).

4.4.1.1.6 Capelin (*Mallotus villosus*)

Annual landings of Barents Sea capelin are presented in Figure 4.3.49. There was no fishery for capelin in the area during 2004-2008 due to poor stock condition, but during 2009-2013 the stock was sufficiently sound to support a quota between 200,000 and 400,000 metric tons. Since 1979, the capelin fishery has been regulated through quotas set using a harvest control rule enforced by the Norwegian-Russian Fishery Commission. The harvest control rule is considered by ICES to be in accordance with the precautionary and ecosystem approaches to fisheries management. Being a forage fish in an ecosystem where two of its predators cod and haddock are presently at high levels, the capelin stock is now under heavy predation pressure. The fishery is restricted to the pre-spawning period (mainly February-March) and the exploitation level is regulated based on a model that incorporates natural mortality, including predation from cod. A minimum landing size of 11cm has been in force since 1979. The management plan's harvest control rule is designed to ensure that SSB remains above the proposed B_{lim} of 200,000 metric tons (with 95% probability). The TAC for 2014 has been set at 65,000 metric tons.

4.4.1.1.7 Polar cod (*Boreogadus saida*)

For economic reasons, there has been little interest to develop a substantial fishery for polar cod. In recent years, the existing fishery has been conducted at a very low level relative to the stock size. Such a low level of exploitation is unlikely to influence the stock condition. Concentrations of polar cod are fished in late autumn during southward spawning migrations along the coast of Novaya Zemlya. In recent years, only Russian fishers have participated in this fishery. No fishery at all was conducted during 2012-2013, however.

4.4.1.1.8 Other finfish species

Information about species composition in Norwegian fisheries north of 67°N is made available through the Norwegian reference fleet (NRF), i.e., 20 high-seas vessels and 20 coastal fishing vessels which have been contracted by the Institute of Marine Research to provide fishery statistics. Table 4.4.1 shows the species composition (percent of total catch by weight) for trawl and longline fisheries conducted by the NRF during 2013. Such fishery data are now routinely collected by these vessels on a daily basis. The impact of these northern-most fisheries on non-regulated species, and the ecosystem as a whole, will be a topic for further research. Figure 4.4.5 shows the location of Norwegian and foreign fishing activity from commercial fleet (larger than 15 m) and fishing vessels used for research purpose in 2013 as reported (VMS) to Norwegian authorities.

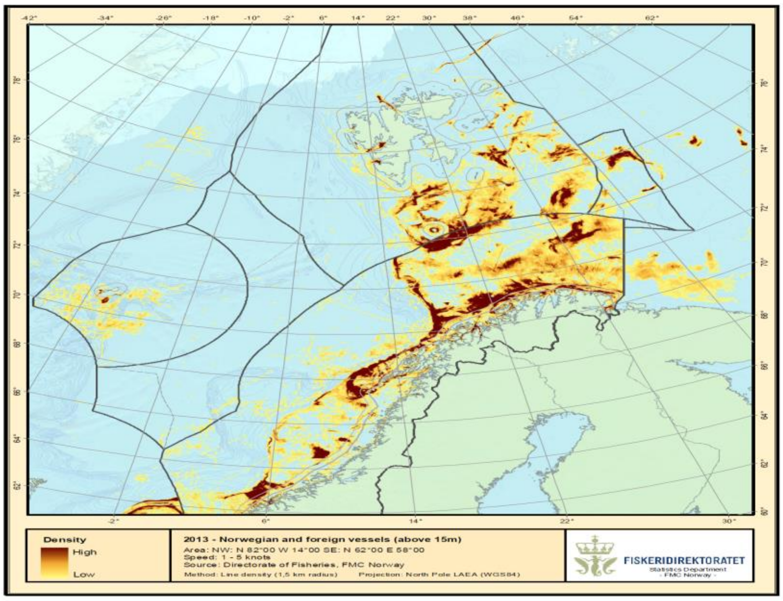


Figure 4.4.5. Location of Norwegian and foreign fishing activity from commercial fleet (larger than 15 m) and fishing vessels used for research purpose in 2013 as reported (VMS) to Norwegian authorities (source: Norwegian Directorate of Fisheries).

Information about total species composition in Russian bottom- and pelagic trawl fisheries in the Barents Sea and adjacent waters during 2013 is available from PINRO based on 20 high-seas fishing vessels with onboard observers (Table 4.4.2). These data were collected from a total of 1,034 days at sea during 2013 yearround in all areas fished by the Russian bottom trawl fleet, with the exception of some waters within Russian and Norwegian EEZs (Figure 4.4.6).

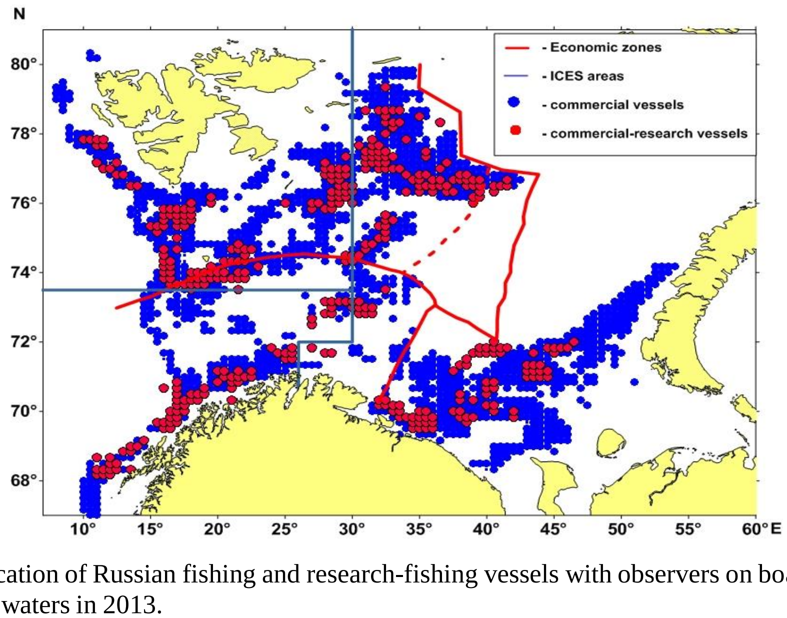


Figure 4.4.6. Location of Russian fishing and research-fishing vessels with observers on board in the Barents Sea and adjacent waters in 2013.

Table 4.4.1. Species composition (percentage of total catch by weight), incl. non-commercial species, in bottom trawl (left) and longline (right) catches done by the Norwegian Reference Fleet north of 67°N during 2013.

Norwegian longline			**Norwegian bottom trawl**	
Species	**W %**		**Species**	**W %**
Cod	64.7		Cod	76.1
Haddock	18.4		Haddock	16.0
Wolffish - Anarhichas minor	4.6		Saithe	5.1
Tusk	3.5		Greenland halibut	1.1
Wolffish- Anarhichas dentkulatus	3.4		Beaked redfish	1.0
Greenland halibut	2.3		Wolffish - Anarhichas minor	0.3
Ling	1.4		Golden redfish	0.2
Golden redfish	0.7		Wolffish - Anarhichas lupus	0.1
Wolffish – Anarhichas lupus	0.3		Ling	+
Amblyraja radiata	0.3		Long rough dab	+
Saithe	0.1		Wolffish - Anarhichas denticulatus	+
Roughhead grenadier	0.1		Tusk	+
Long rough dab	+		Atlantic halibut	+
Atlantic halibut	+		Amblyraja radiata	+
Skates unspec.	+		Whiting	+
Chimaera monstrosa	+		Flounder	+
Greater forkbeard	+		Argentina silus	+
Beaked redfish	+		Lumpsucker	+
Blackmouth catshark	+		Raja clavata	+
Spinetail ray	+		Smaller redfish	+
Round ray	+		Roundnose grenadier	+
Sailray	+		Roughhead grenadier	+
Anglerfish	+		Greater forkbeard	+
Arctic skate	+		Rajella fyllae	+
Redfish unspec.	+		Bathyraja spinicauda	+
Blue ling	+		Chimaera monstrosa	+
Whiting	+		Plaice	+
Greater eelpout	+		Herring	+
Plaice	+		Greater eelpout	+
Mora	+		Blue whiting	+
Velvet belly lantern shark	+		Blue ling	+
Roundnose grenadier	+		Argentina silus	+
Longnosed skate	+		Anglerfish	+
Hake	+		Megrim	+
Spurdog	+		Lemon sole	+
Argentina silus	+		Witch flounder	+
Smaller redfish	+		Hake	+
Greenland shark	+		Mackerel	+
Lumpsucker	+			
Pollock	+			
Mackerel	+			

Table 4.4.2. Species composition (percentage of total catch by weight) of removals by Russian trawlers in the Barents Sea during 2013. Includes non-commercial species caught in bottom and pelagic trawls. Data were collected for PINRO by on-board observers.

Russian 2013 bottom trawl survey data.

Species	W %
Cod	75.4
Haddock	14.6
Greenland halibut	5.1
Saithe	4.0
Wolffish - *Anarhichas minor*	0.2
Wolffish - *Anarhichas lupus*	0.3
Beaked redfish	0.1
Long rough dab	0.2
Wolffish - *Anarhichas dentikulatus*	0.1
Golden redfish	0.1
Capelin	+
Plaice	+
Polar cod	+
Herring	+
Thorny Skate - *Amblyraja radiata*	+
Ling	+
Tusk	+
Lumpsucker	+
Rabbit fish - *Chimaera monstrosa*	+
Anglerfish	+
Blue whiting	+
Norway pout	+
Greater argentine - *Argentina silus*	+
Common sole	+

4.4.1.2 Discards

Although discarding is prohibited for fisheries conducted in the Barents Sea, inevitably some discarding does occur; the level of which is not reported. Hence, estimates of discard are not incorporated in fish stock assessments. Lack of discard estimates results in stock assessments which are less precise, less accurate, and less reliable. Hence, the impact of fisheries on the ecosystem is not fully understood. One possible approach to estimate the amount of discarded fish is to analyze landings data, i.e., size-weight composition of landed catch relative to data collected by observers or contracted fishermen onboard commercial vessels. In 2012-2014, Norway conducted a pilot project testing methods to estimate discard in selected fisheries, with the goal to establish methods to estimate discard on a routine basis for all Norwegian fisheries in the near future. Preliminary results from selected fisheries have been considered. As a consequence Norway has established a procedure to account for unreported cod bycatch in the Barents Sea capelin fishery by allocating a small part of the Norwegian cod quota to compensate. Furthermore, the quantity of cod discarded in the coastal gill-net fishery (small vessels less than 15m) was approximately 0.3 % of the landed quantity. Work is ongoing to develop methods to estimate discard for trawlers and longliners.

Since 1984, reports of redfish (primarily *S. mentella*) taken as bycatch and then discarded in the Norwegian shrimp fishery indicate that shrimp trawlers removed significant numbers of juvenile redfish at the beginning of the 1980's. This bycatch peaked in 1984, when it amounted to about 640 million individuals, a number that might equal a good year class for this stock (Figure 4.4.7). After the sorting grid became mandatory in 1993, bycatch of redfish was reduced dramatically. Reports also indicate that closures of fishing areas are necessary to protect juvenile redfish, since they are not sufficiently protected using sorting grids. Cod bycatch and discard consist mainly of 1- and 2 year-old individuals, but is generally small compared to other reported sources of mortality, i.e., fisheries catch including discard, and cannibalism.

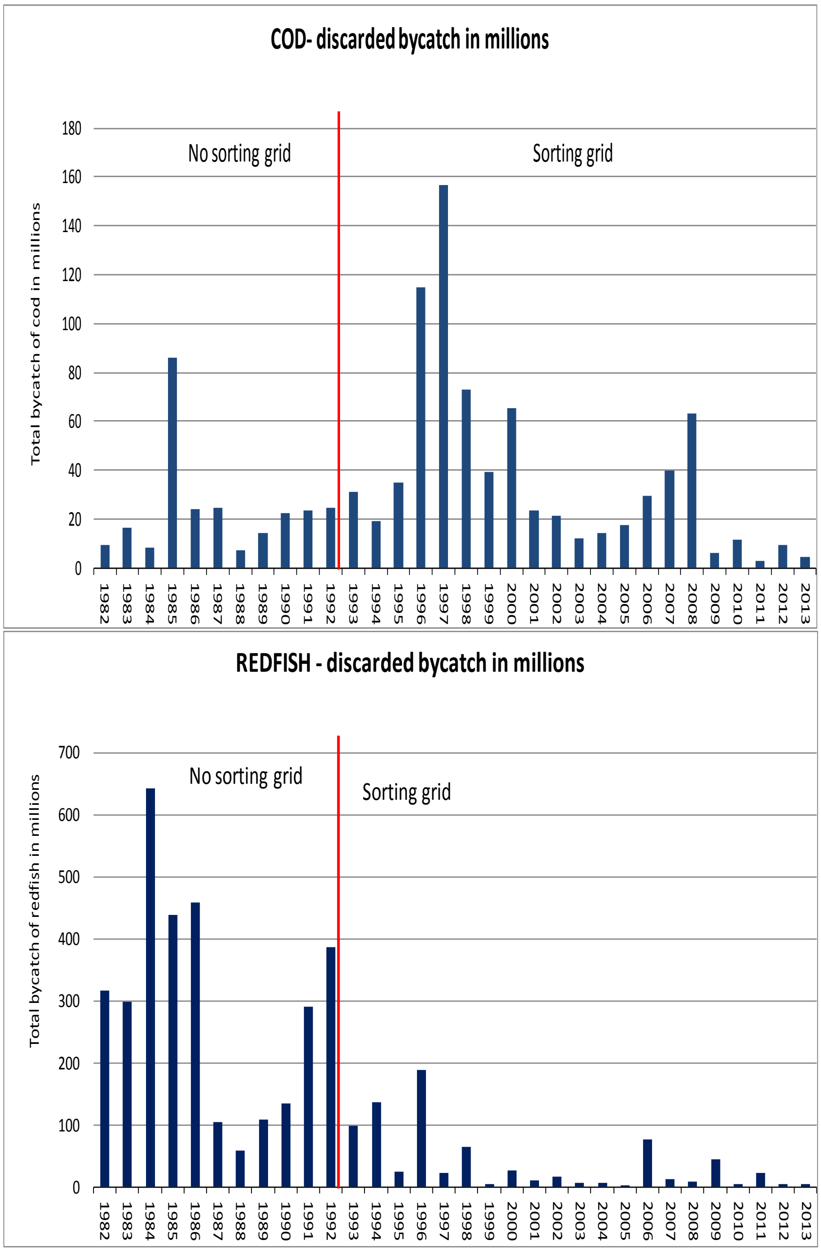


Figure 4.4.7. Bycatch (discards) estimates of small cod (upper) and redfish (lower) during the Barents Sea shrimp fishery (1982- 2013) before and after the introduction of the sorting grid in 1992.

Significant discard of cod also occurred in the Barents Sea shrimp fishery after the introduction of the sorting grid (Figure 4.4.7). Cod bycatch has declined in recent years to less than 3 million individuals. Discard of haddock in the Barents Sea shrimp fishery follows the abundance of I-group haddock in the winter bottom trawl survey, and indicates the highest haddock discard in 2007 of about 250 million individuals. In recent years the haddock discard has been about 10-20 million per year.

4.4.1.3 Shellfish

4.4.1.3.1 Northern shrimp (*Pandalus borealis*)

Norwegian and Russian vessels exploit the stock over the entire resource area, while vessels from other nations are restricted to the Svalbard fishery zone. No overall TAC has been established for this stock, and the fishery is partly regulated by effort control, licensing, and a partial TAC (Russian zone only). Bycatch is constrained by mandatory sorting grids and by temporary closures of areas where high bycatch occurs of juvenile cod, haddock, Greenland halibut, redfish, or small shrimp (< 15 mm). The minimum mesh size is 35 mm.

A major restructuring of the fleet toward fewer and larger vessels has taken place since the mid-1990s. Since 1995, the average engine size of a shrimp vessel in ICES Subareas I and II has increased from 1000 HP (horse powers) to more than 6000 HP in the early 2010s, and the number of vessels has markedly declined. Overall catches have decreased since 2000 reflecting reduced economic profitability of the fishery. In 2012, 25,000 tonnes were caught. The 2012 stock assessment indicated that the stock has been exploited in a sustainable manner and has remained well above precautionary reference limits throughout the history of the fishery. ICES advised that catches of 60,000 tonnes in 2014 would maintain the stock at the current high biomass. The reported landings of shrimp in 2013 were about 23,000 tonnes, i.e., about one third of the scientific recommended allowable catches (Hvingel, 2014).

The bulk of the shrimp biomass has, however, in recent years been found further east in the Barents Sea (Figure 4.4.8). Catches on some of the traditional and more westerly fishing grounds have therefore declined. Recent reports from fishermen show lower catch rates than might be expected from the overall positive state of the stock. This should be seen in connection with the before mentioned depletion of some of the traditional fishing grounds and the cost of a relatively small fleet of finding new grounds with commercial interesting concentrations of shrimp.

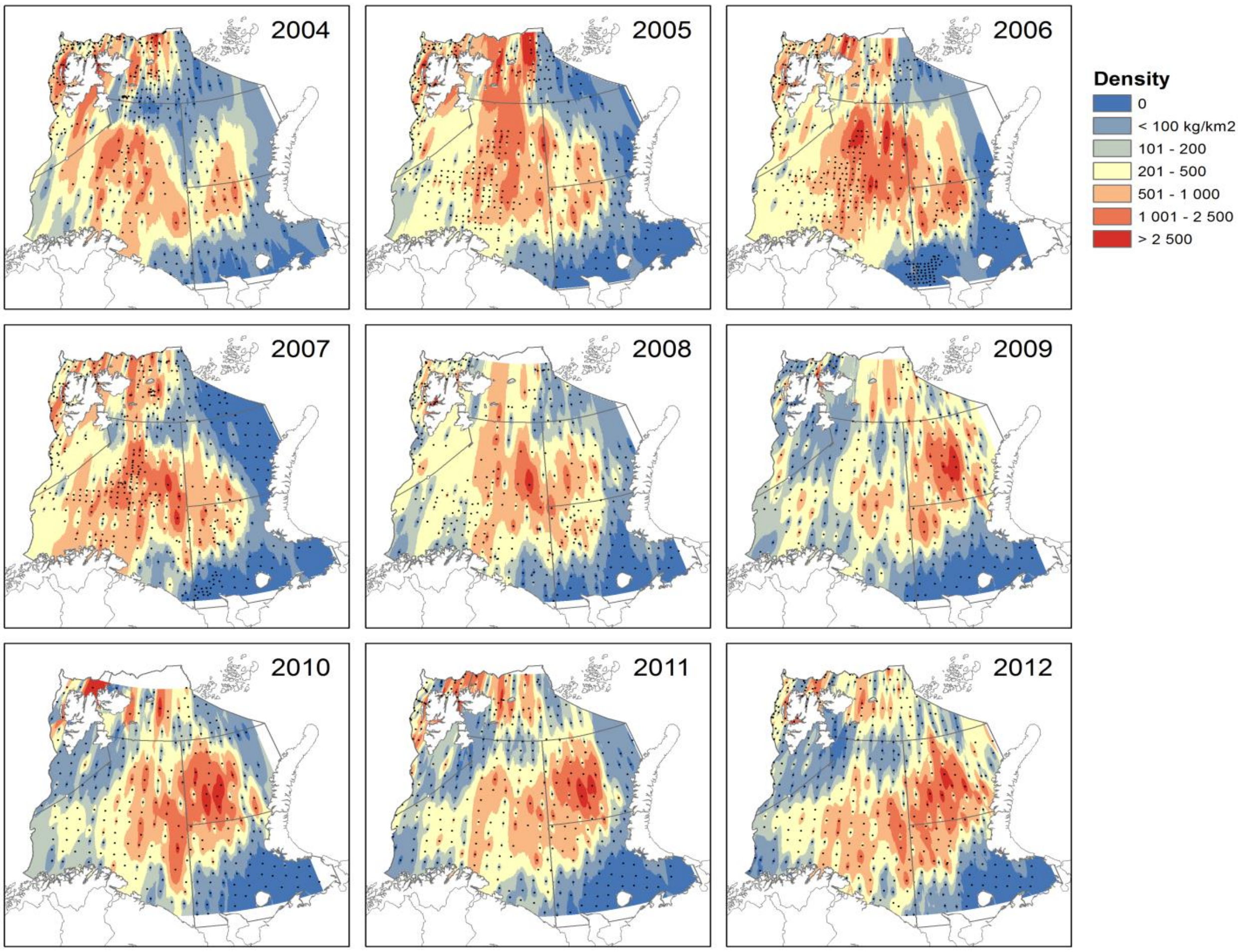


Figure 4.4.8. Shrimp density by year from inverse distance weighted interpolation (e.g. Fisher *et al*., 1987) between trawl stations (black dots) in the Joint Russian-Norwegian Ecosystem survey (Europe Albers Equal Area Conic projection).

4.4.1.3.2 Red king crab (*Paralithodes camtschaticus*)

In the area east of 26°E and south of 71°30'N, and in Russian waters of the Barents Sea, the commercial crab fishery is managed to achieve long-term sustainability by setting annual quotas for this area. Outside this area (west of 26°E), the red king crab fishery is regarded as undesirable; a free non-legislated fishery is permitted, and release of viable crabs back into the sea is prohibited. In the Norwegian waters of the Barents Sea, the harvest rate of this species in the quota-regulated area is high; this is intended to keep the standing stock as low as possible to limit further spread of the crab. Both male and female crabs above a minimum legal size (CL > 130mm) are taken in the quota-regulated fishery, and there are no seasonal catch restrictions. Hence, Norwegian management of this fishery contradicts management regimes applied in both the Bering Sea (Alaska) and in the Russian part of the Barents Sea. During 2013, 474 Norwegian vessels participated in the quota-regulated fishery (Sundet, 2014). The quota was 900 tonnes male crabs, and the catch was approximately 1,000 tonnes.

4.4.1.3.3 Snow crab (*Chionoecetes opilio*)

The stock of snow crabs in the Barents Sea has potential to support a fishery comparable in value to the famous cod fishery. Since the first Snow crabs were discovered in the Eastern

Barents Sea in the mid 1990s the stock has grown rapidly and is now ready for commercial exploitation. Model simulations indicate potential annual catches to reach the 25,000-75,000 tonnes range within the next 10 years (Hvingel and Sundet, 2014). Two commercial fishing vessels fished for snow crab in international waters of the Barents Sea during 2013 using traps, and catch rates were of commercial interest. The official Norwegian landings were about 190 tonnes.

4.4.1.4 Important indirect effects of fisheries on the ecosystem

The resilience of the Barents Sea ecosystem, even unexploited, may be low due to great climatic changes (Loeng and Drinkwater, 2007), variability in primary production and biomass/production of organisms at different trophic levels. Heavily exploited populations of top predators influence many lower trophic levels of the ecosystem. Overfishing of small pelagic fish, i.e. capelin, results in imbalance of energy flow passing to the higher trophic levels; this may have the similar strong consequences for the ecosystem as overfishing of top predators (Yaragina and Dolgov, 2009).

Fisheries in the Barents Sea not only influence the stocks targeted. Due to strong species interactions, removal of one stock may influence the abundance of other stocks through fishery-induced changes in food supply, competition for food, and predation pressure. Reductions in stock size due to fishery removals may also lead to changes in migration pattern. Density-dependent migrations may cause fish stocks to cover greater areas and travel longer distances when abundance is relatively high. Fishing pressure may also reduce the average age and/or size of a stock, and may also reduce the average age at maturity.

Qualitative effects of trawling on benthic organisms have been studied to an extent. The challenge for management is to determine fishing levels which ensure that fisheries are both profitable and sustainable over time. The difficulty lies in the fact that both profitable fishing and sustainable fishing depend on maintaining the integrity of benthic fish habitats. To determine the total impact of trawling, extensive mapping of both fishing effort and bottom habitat would be necessary. The most serious effects of trawling have been demonstrated for hard bottom habitats dominated by large sessile fauna. Organisms which erect structures and dwell in colonies — sponges, anthozoans, and corals — have shown considerably reduced abundance in the wake of bottom trawl gear. Accordingly, hard bottom substrates in the Barents Sea providing habitat for such large epifauna should be identified and protected (Løkkeborg and Fosså, 2011).

Trawling effects on soft bottom have been less studied, and consequently there are large uncertainties associated with the effects of fisheries on these habitats. Studies on impacts of shrimp trawling on clay-silt bottoms have not demonstrated clear and consistent effects, but potential changes may be masked by the more pronounced temporal variability in these habitats (Løkkeborg, 2005). The impacts of experimental trawling have been studied on a high seas fishing ground in the Barents Sea (Kutti et al., 2005.) Trawling seems to affect benthic assemblages mainly through re-suspension of surface sediments, and the disturbance of shallow burrowing infaunal species on the seafloor.

During 2009-2012, joint research between Norway and Russia was conducted to explore the possibility of using pelagic trawls when targeting demersal fish species. Pelagic trawl should minimize the impact on bottom fauna, and reduce bycatch. During these exploratory fishery operations, it was mandatory to use sorting grids and/or trawls with square mesh in the top panel of the cod end — this more stable four-panel trawl geometry was used to avoid catching undersized fish.

After four years of exploratory fishing with pelagic trawls, use of this gear to fish for cod, haddock, and other demersal fish species is still not allowed — primarily due to smaller size fish being captured (on average), and a tendency toward large trawl hauls too big to handle without difficulty. The experiment has, however, led to advances in the design of bottom trawls, including: bigger trawl openings; better size selection; and escapement windows to avoid excessive catch sizes.

Lost gears, such as gillnets, may continue to catch fish unintentionally for a long time (ghost fishing). The catch efficiency of lost gillnets has been examined for some species and areas (*e.g.* Humborstad et al., 2003; Misund et al., 2006; Large et al., 2009), but at present no estimate of the total effect is available. Ghost fishing at depths shallower than 200m is considered not to be a significant problem due to lost, discarded, or abandoned nets having a limited fishing life: they tend to have a high rate of biofouling that causes their netting to become clogged; and, in some areas, tidal scouring speeds their erosion. Investigations conducted by the Norwegian Institute of Marine Research during 1999-2000 demonstrated that the number of gillnets lost increases with depth. Indications also were that of all Norwegian gillnet fisheries the fishery for Greenland halibut is where most nets are lost. The effects of ghost fishing in deeper waters, e.g. for Greenland halibut, may be greater since ghost fishing may continue for periods of 2–3 years or longer, largely due deeper waters have lower rates of biofouling and tidal scouring. Since 1980, the Norwegian Directorate of Fisheries conducted annual surveys to retrieve lost or abandoned fishing gear. A total of 10,784 gill nets of 30m standard length (approximately 320km) were retrieved from Norwegian fishing grounds during 1983- 2003. The 2013 gear retrieval survey retrieved and brought back to land about 900 gillnets, 3 shrimp trawls, 22 km of longlines, 12km trawl wire, 5km of ropes, and several bits and pieces of different nets, traps, dredges and chains. It is still the deep-water gillnets used to catch Greenland halibut that contribute most to the ghost fishing.

Other types of fishery-induced mortality include: slipping — where pelagic catch is released too late to ensure survival; burst nets; and that caused through encounters with active fishing gear, such as escape mortality (Suuronen, 2005; Broadhurst et al., 2006; Ingólfsson et al., 2007). Some small-scale effects have been demonstrated, but population-level effects are not known.

In Barents Sea trawl fisheries, harp seals occur as bycatch and often die in the trawl (Zyryanov et al., 2004), whereas other seal species occur only occasionally as bycatch in trawls. In addition, during years with low capelin abundance, harp seals migrate into coastal waters in search of alternative food sources; this migration coincides with the winter gillnet fishery for immature cod along Norwegian coast in the Barents Sea. In 2004, Norway initiated a monitoring program for bycatch of marine mammals in fisheries. Using data collected during 2006–2008 from a monitored segment (18 vessels) of the Norwegian coastal fleet (vessels <15 m) of gillnetters targeting monkfish and cod, Bjørge et al. (2013) estimated bycatch of about 6,900 harbor porpoises taken annually in the coastal monkfish and cod gillnet fisheries. Despite the relatively large abundance of dolphins in the Barents Sea, they are not often caught in trawls (Haug et al., 2011).

Fisheries impact seabird populations in two different ways: 1) directly, through bycatch of seabirds in fishing equipment; and 2) indirectly, through competition with fisheries for the same food sources. Documentation of the scale of seabird bycatch in the Barents Sea is patchy. Particular incidents such as bycatch of large numbers of guillemots during spring cod fisheries in Norwegian waters have been documented (Strann et al., 1991). Gillnet fishing affects primarily coastal and pelagic diving seabirds, while surface-feeding seabirds are most vulnerable to longline fishing (Furness, 2003). The population impact of direct mortality through bycatch will vary with the time of year, the status of the affected population, and its sex and age structure. Even low levels of bycatch mortality may be a threat to red-listed species such as common guillemot, white-billed diver, and Steller’s eider. Several bird scaring devices have been tested for longline fisheries; a simple bird-scaring line not only significantly reduces seabird bycatch, but also increases fish catch by reducing bait loss (Løkkeborg, 2003). This creates an economic incentive for the fishermen to use it, and often results in the bird-scaring line being used without any forced regulation when seabird bycatch is a problem.

In 2009, the Norwegian Institute for Nature Research (NINA) and the Norwegian Institute of Marine Research (IMR) began a cooperation to develop methods to estimate seabird bycatch. Total estimated seabird bycatch amounts to about 3,000 birds per year for both the large coastal cod-haddock fisheries and the much smaller lumpfish fisheries in Northern Norway (Fangel et al., 2015).

4.4.1.5 Evolutionary effect of fishing on maturity in cod

Age at first reproduction has declined markedly for Barents Sea cod over recent decades. In the 1940s, a cod typically reproduced for the first time when it was between 9 or 10 years old. In the 1990s, average age at first reproduction had declined to between 6 and 7 years. Reduced age at maturity may affect the reproductive capacity of the cod stock, and the cod’s role as an important top predator in the ecosystem. The possible explanation for the declining age at maturation in Northeast Arctic cod is an adaptive response to high fishing pressure through many years and thus involves genetic changes in the population (Law and Grey, 1989; Jørgensen et al., 2009). Because the number of offspring that a cod can produce increases considerably with body size, older fish generally produce more offspring than young fish. Moreover, the eggs spawned by older cod are more viable than those from younger cod, thus the reproduction potential of the stock has been negatively affected by the development (see Sundby, 2000) for references). This may have significant consequences for cod recruitment and the role of cod as a top predator in the ecosystem. In addition, the decline in average age at maturity has caused the spawning stock to be made up of fewer age groups. This has made recruitment more dependent on environmental factors in recent decades compared to previous times when more age groups of older fish participated in the spawning (Ottersen et al., 2006). It should be noted that fisheries targeting larger more marketable sized individuals also reduces the age structure of the population, but additional evolutionary effects may exacerbate the causes of poor stock condition making it more difficult, and requiring longer time periods, for the stock rebuild if fishing pressure is reduced.

4.4.2 Oil and gas activities

O. Korneev (SMG), O. Raustein (NPD), A. Ovsyannikov (SMG), and A. Bambulyak (Akvaplan niva)

The environmental risks of oil and gas development in the region have been evaluated several times, and is a key environmental question facing the region. The focus of the debate is the risk of an accidental oil-spill during exploration or production. The consequences of such a spill depend on the activity, the location, time and potential exposure of environmental valuable species and areas. One of the environmental risks from future oil production can be associated with potential activities, which might influence near-shore areas, especially in ecologically valuable areas like the Lofoten-Islands and Pechora Sea. In addition, the Polar Oceanographic Front and the Ice Edge zone are particular sensitive areas.

4.4.2.1 Seismic surveys

Seismic activities can affect survival of fish, but this effect is limited to individuals closer than 5 meters from the sound source. Modelling studies have shown no population effect of seismic induced mortality at the larval stage of fish. Fish behaviour can also be affected by seismic activities, and this effect can extend more than 30km from the seismic vessel. Marine mammals generally escape from area where seismic activities take place. In addition, communication between mammals may be affected by seismic activities. The overall impact from these behavioural effects is not fully known.

4.4.2.2 Operational discharges

Results from environmental monitoring have so far shown no effects from operational discharges into the water column.

4.4.2.3 Accidental discharges

There have been no reports of significant accidental discharge of oil or chemicals in the Barents Sea so far.

Risk of accidental discharges

The following discussion addresses the risk of accidental discharges from oil and gas together with risks of discharge from ship transport. Thus, the analyses below involve more than the risk from oil and gas activities alone.

Patin (2008a) evaluated the possible rate and volume of accidental oil spills in Russian westard Arctic seas based on the average worldwide oil spill statistics. Results of generalized relevant statistical data are presented in Table 4.4.3. It should be noted that this represents one of several methods which could have produced different results. As the study is based on worldwide data, it should be interpreted with special caution at regional or local levels. It should also be noted that risk assessment is an area with considerable debate regarding methodology. Current and planned activities for the Russian oil industry in the Barents Sea suggest a number of objectives, facilities, and situations which could lead to accidental oil spills.

Table 4.4.3. Average parameters of oil input into the marine environment from accidental spills according to worldwide statistics (1990-2000) (Patin 2008b).

Spill sources	Total worldwide amount tonnes/year	Initial worldwide	Average specific oil release from tonnes/year	Input per 1 million tonnes of transported oil tonnes	Number of oil spills per 1 million tonnes transported oil
Operations on platforms	600	6000 platforms	0.1 per 1 platform	0.5	1*
Transportation by pipelines	2800	150000 km	0.02 per 1 km	<2	1**
Transportation by tankers	100 000	7300 tankers	14 per 1 tanker	30	$4x10^{-3}$

* Spills over 17 tonnes. ** Spills less than 3 tonnes. *** Spills over 5,000 tonnes.

Assessment results suggest that the probable total accidental input of oil into marine environments during the process of developing hydrocarbon fields in Western Arctic seas could reach 23,000 tonnes by 2030, with tanker accidents being the main source (Table 4.4.4). Taking into account routine (operational) releases and illegal discharges of oil wastes during shipping — which is comparable in amount to accidental spills (Patin, 2008b) — total oil input by 2030 is estimated to be about 40,000 tonnes. It should be noted that a planned multiple increase in oil export (up to 10 times) by tankers from Russian Arctic terminals should be taken into account. Current oil export is about 15 million tonnes per year. During the next 30 years the total amount of oil export/transport from Arctic will probably exceed 1 billion tonnes. Accordingly, it can be predicted that the total (cumulative) input of oil into the marine environment will reach 100,000 tonnes by 2030.

The probability of oil spills is highly variable relative to the amount of oil spilled and the particular situation. By 2015, maximum capacity of oil transportation from the Western Arctic by tankers was estimated to reach ≈125 million tonnes/year (Bambuhak and Frantzen, 2009).

Worldwide loss due to spillage is estimated to be about 30 tonnes per 1,000,000 tonnes of oil transported (Table 4.4.3). Based on this, the total probable amount of oil spilled was estimated at ≈3,750 tonnes/year.

Based on this estimate and a worldwide statistical parameter for large spills (4×10^{-3} spills per 1 million tonnes of transported oil) (GESAMP, 2007) one may predict an oil spill rate of about 0.6 large spills (over 5,000 tonnes) per year. Vorobiev et al. (2005), projects that catastrophic oil spills with serious ecological effects in the Arctic seas may occur as often as every 5-10 years. It should be noted, however, that no major oil spills have occurred thus far from marine oil transport in the Barents Sea.

From a biogeographical point of view, the highest risk of incidents and the most serious impacts of oil spills may be attributed to numerous bays, inlets, creeks, and marshes in Arctic coastal zones. These areas are distinguished by high biomass and productivity, and in Russia many of them have received the status of "Especially protected Arctic marine territories".

Table 4.4.4. Extrapolation assessments of amount and rate of oil spills during development of hydrocarbon fields in the Western Arctic Seas under planned cumulative production of oil up to 700 million tonnes by 2030.

Spill sources	Total amount of spill		Rate of large oil spill (over 5,005 tonnes)
	Tones	**%**	
Operations on platforms	400	1	1-10 spills per 10 000 wells
Oil transportation by pipelines	1400	7	10^{-3} - 10^{-5} spills/year per 1 km pipeline
Oil transportation by tankers	21000*	92	4×10^{-3} spills per 1 million of transported oil
Total	22800	100	

* Including spills in ports and oil terminals

Overall risk

Risk analysis is a decision support tool and an integral part of risk management; it is often calculated as the product of probability and consequence. Risk analysis seeks to understand how a dangerous situation can arise and develop; this facilitates the implementation of relevant measures which will help prevent risks, minimize the number of accidents, and limit the consequences if accidents do occur.

The environmental risk from accidental oil spills depends on a number of factors. The most important of these are the probability of an oil spill, the magnitude of a particular spill, the geographical position in relation to vulnerable areas and resources, when the incidence occurs in relation to periods when vulnerability to oil spill is particular high. The efficiency of established barriers and response system, which may vary considerably depending on the weather conditions at the time, is another important factor.

Currently, a number of models and analyses are used to estimate risk. These focus on different aspects of risk, such as the probability of accidental discharges, the probability of oil contamination, the risk of damage, and the risk of damage-related costs. Each sector and each activity must use risk management to prevent oil spills, and establish adequate barriers and/or emergency response systems. Models used to calculate risk also demonstrate that the potential damage, and thus the environmental risk, depends on the degree to which valuable and vulnerable areas and resources may be affected by oil spills. For management purposes, it is important to develop a common understanding of risk, including an understanding of mechanisms that create risk, and also the limitations and uncertainty of our knowledge.

4.4.2.4 Physical disturbance of the seabed habitat reduction

Effects on bottom habitats from oil and gas activities are limited to the Snøhvit field and Prirazlomnoe field and are small also within this field.

4.4.2.5 Emissions to air

Offshore oil and gas production will contribute to air emissions of CO_2, NO_x, non-methane volatile organic compounds (NMVOC), methane, soot (black carbon), and SO_2. Air emissions from petroleum production result from energy production, gas flaring, and venting — the release of unburned gas from pipes and valves during normal or safety operations.

The impact of these emissions is discussed in chapter 4.4.3 – Pollution.

4.4.2.6 Expected situation in the near future (5 years)

It was expected that several new wells will be drilled in the Norwegian and Russian sectors of the Barents Sea during 2015.

The Norwegian Ministry of Petroleum and Energy has announced the 23rd licensing round. The round consists of 57 blocks, or parts of blocks. These are distributed with 34 blocks in the south-eastern Barents Sea (the formerly disputed area towards Russia), 20 blocks in other parts of the Barents Sea and three blocks in the Norwegian Sea. The government aims to award new production licences in the first half of 2016.

According to operator licence agreements during the period leading up to 2024, plans are to conduct 48,200 linear km of 2D and 21,650 square km of 3D seismic surveys, and to drill 7 exploratory and 27 prospective wells at 28 areas within the Barents and Pechora Seas.

By 2020, “Gazprom Neft Shelf” company plans to reach ≈5 million tonnes of oil extraction per year from the Prirazlomnoe field. By 2030, “Shtokman Development AG” plans to reach ≈71 mln. m^3 per day of gas extraction from the northwestern part of the South Barents Basin in the Russian zone.

The Barents Sea hydrocarbon industry will be based on supply from currently existing fields (oil: Prirazlomnoye, Medynskoe, Varandey, Dolginskoye / oil/gas condensate: Severo-

Gulyaevskoe). Current amounts of oil extracted from structures and fields approximate 600-700 million tonnes. The gas industry is based on Shtokman and Ledovoe gas condensate fields, together with the Ludlovskoe gas field; total annual production is estimated to be 400 billion cubic meters. Extraction operations will be further developed according to exploration results in nearby fields. Plans are to build an underwater pipeline — over 800km in length — to transport gas condensate from the Shtokman field; this may disturb bottom sediments along the coastline.

4.4.3. Pollution

C.F. Pettersen (NEA) and A. Rybalko (SMG)

Monitoring results confirm that the Barents Sea environment is generally a clean sea area with relatively low contaminant levels, with a few exceptions. The status of contaminants in the Barents Sea is based on current knowledge. There is a lack of long-term data for many components, and there is only limited knowledge available especially on bioaccumulation, bio magnification, and metabolic degradation of pollutants through the nutrient chain. Another matter of concern is distribution and content of radioactive substances in the marine environment which may pose major risks to the whole ecosystem. This chapter presents monitoring results from the Barents Sea.

4.4.3.1 Current status and trend for POPs

C.F. Pettersen (Norwegian Environment Agency), P.B. Nizzetto (NILU), S. Boitsov (IMR), and J. Klungsøyr (IMR)

Air

Atmospheric transport is believed to be the most important transport route for volatile and semi-volatile POPs (persistent organic pollutants) into the Arctic (AMAP 2004). Monitoring POPs in the air at Zeppelin observatory (close to Ny Ålesund, Svalbard) has revealed low concentrations with stabile or declining trends. One exception is HCB (hexachlorobenzene) that has increased significantly since 2003 (Nizzetto, 2014). Increasing concentrations of HCB may result from evaporation of remobilized HCB from open-ocean surface waters along the western coast of Spitsbergen (Svalbard) which has been ice-free during the past decade (Hung et al., 2010; Ma et al., 2011). While pollutants such as HCB, HCH (hexachlorocyclohexane), PCB (polychlorinated biphenyl), and PBDE (polybrominated diphenyl ether) occur at higher levels at Zeppelin, compared to the levels found at Andøya in 2013, the highest concentrations of PFAS (polyfluorinated alkyl substances) and DDT (dichlorodiphenyl trichloroethane) were found at Andøya in 2013 (Nizzetto, 2014).

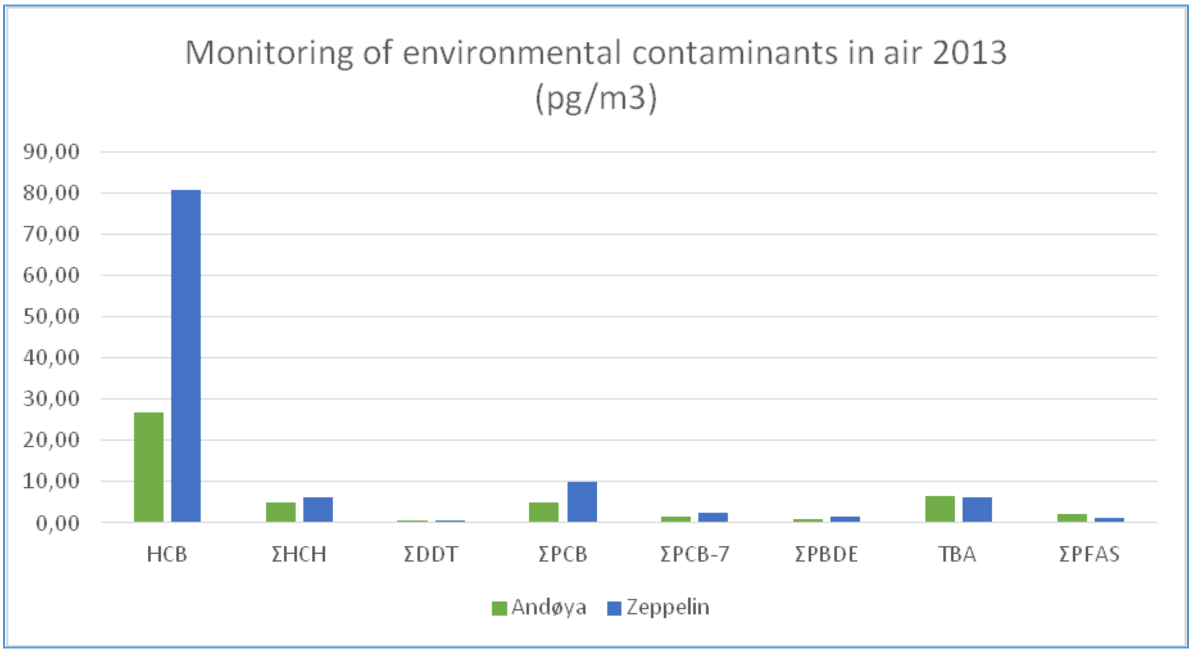


Figure 4.4.9. Environmental pollutants such as HCB, HCH, PCB and PBDE occurred at higher levels at Zeppelin, compared to Andøya in 2013. The highest concentrations of PFAS and DDT were found at Andøya in 2013 (Nizzetto, 2014).

Concentrations of HCH during 2013 were in the same range at both observatories and followed the decreasing trends from previous years. Overall, HCHs are compounds which have shown the largest decrease since the beginning of the air monitoring at Zeppelin (a factor of 15). Annual mean concentrations of PCB are similar or slightly lower than in 2012 at Zeppelin and Andøya. Stable concentrations have been observed at Zeppelin during the last 3 years, but have decreased by a factor of 2-3 during the previous 5-10 years. Concentrations at Andøya follow a declining trend also in recent years, which results in larger differences compared to Zeppelin. PBDE levels were highest at Zeppelin and lowest at Andøya during 2013, and concentrations were higher than in 2012 at both stations (Figure 4.4.9). The concentration of sum PBDE at Zeppelin was the highest since 2007. No significant long-term trend of sum PBDE is measurable at any of the observatories. Concentrations of DDT at Andøya and Zeppelin were similar or slightly lower during 2013, compared to earlier years (Figure 4.4.9). This was also consistent for all congeners. The long-term monitoring at Zeppelin shows a significant reduction of the air concentrations of DDT. A strong seasonality was found at Zeppelin with 3-6 times higher concentrations in winter time (December-January) compared to warmer months (April-September). The levels of PFAS at Andøya were higher in 2013 compared to 2012 and 2011, while the concentrations at Zeppelin were the lowest since the monitoring was initiated in 2006. Monitoring results correspond to their anthropogenic applications and current use; and thereby with strong contributions of ongoing emission from primary sources. There is large variability in levels from year to year, and no strong evidence of decreasing trends. Monitoring shows no seasonal trends, and that concentrations of siloxanes at Zeppelin are 100 to 1,000 fold higher than levels of legacy POPs (Nizzetto et al., 2014).

Riverine inputs of POPs to the Barents Sea

Concentrations of PCBs were found to be lower in river Pasvik, compared to rivers in the south-eastern parts of Norway (Kaste et al., 2012).

Seafood

For most monitored substances in the Barents Sea, levels of contamination in seafood are well below limit values for human consumption. There is one important exception for dioxins and dioxin-like polychlorinated biphenyls in cod liver. Comparison of POP measurements in Atlantic cod from 1991-93 in the Barents Sea to Atlantic cod from 2007 in Northern Norway showed no change in PCB levels, a slight decrease in DDT and HCB, and decreases in HCH and chlordans (Sange and Klungsoyr, 1997; Bustnes at al., 2012). For dioxins and dl-PCBs the databases on levels in commercial fish has improved substantially since 2006. There is a decreasing trend of dioxins and dl-PCBs in the environment and therefore also in food. A decrease in exposure to dioxins and dl-PCBs from fish can be seen since 2006, as present exposure is estimated to be in the range of 40% of the exposure calculated in 2006. The decrease is likely due to a combination of more data on levels of dioxins and dl-PCBs in fish in 2014 than in 2006, and decreased levels of dioxins and dl-PCBs in the environment (VKM, 2014). Further, it is known that the levels of dioxins and dioxin-like (e.g. planar) PCBs are highest near the Norwegian coast and decreasing northward towards Svalbard.

In the western Barents Sea, IMR has conducted a monitoring program of organochlorine pesticides (OCs) such as HCHs, HCB, DDTs, and chlordanes in fish liver (various species). A relatively new group of emerging pollutants, brominated flame retardants of the type PBDE (polybrominated diphenyl ethers) has been monitored since 2009. Results over the last 12 years of cod and haddock monitoring are presented in Table 4.4.5.

Table 4.4.5. Range in average concentrations of selected POPs in fish liver per year, in µg/kg ww. (Data from IMR measurements 2000-2012)**.**

	HCHs	DDTs	PCB7	PBDEs
Atlantic Cod	1-10	70-200	80-190	6*
Haddock	2-10	10-60	30-120	3-5

*PBDE in codfish liver from the Barents Sea was measured in 2012 only.

Most compounds studied are found at background levels. For DDT in Atlantic cod (Gadus morhua) liver, the highest levels found fall into Class II of the classification system established for this group of contaminants by the Norwegian Environment Agency. This corresponds to “good condition” (the green line in Figure 4.4.10 below), i.e. concentrations above the background level but below any thresholds for possible effects. For PCB7, even highest levels in cod fall into Class I, “background” (the blue line in 4.4.10). The classification system has only been established for cod liver.

Figure 4.4.10 also shows trends observed over time. Both for PCB7 and DDTs, both average and maximum concentrations seem to be decreasing since 2004, although PCB7 concentrations seem to have reached a minimum in 2009 and were slightly higher in 2012.

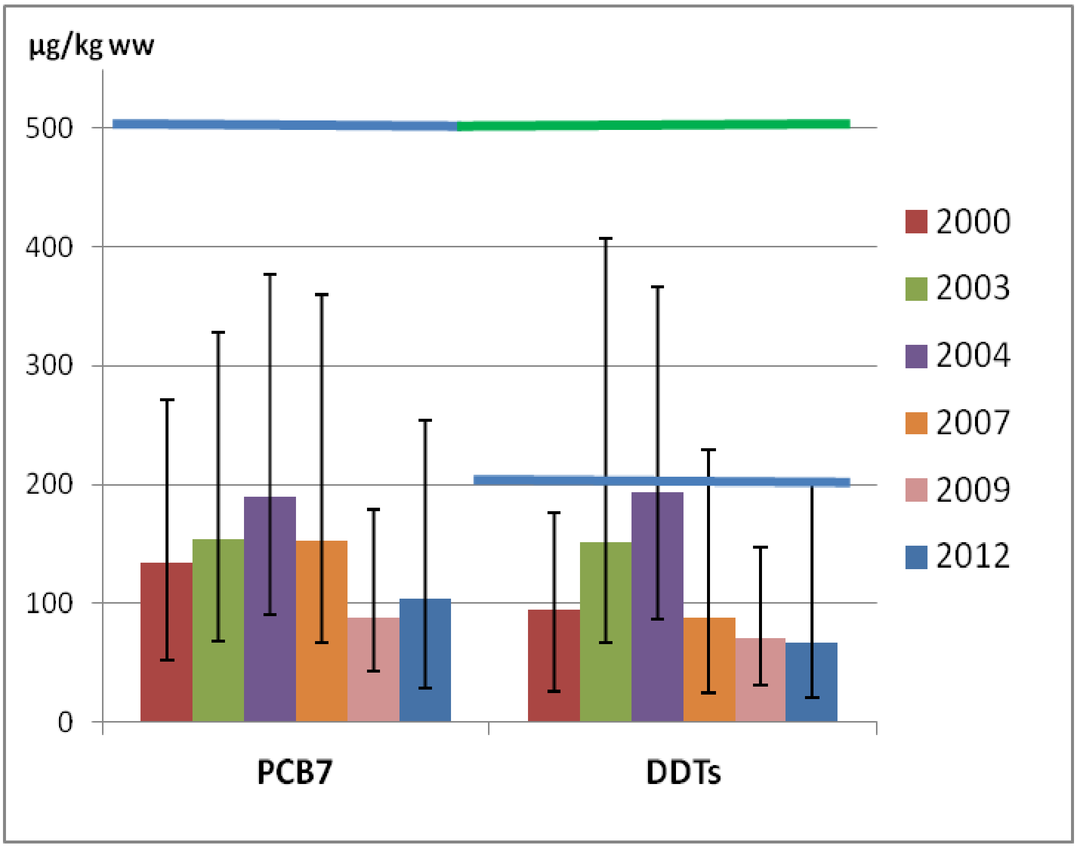


Figure 4.4.10. PCB7 and DDTs concentrations in codfishliver from the western part of the Barents Sea in the period 2000-2012 (IMR data). Coloured bars show average concentrations per year, while black bars indicate the maximum and the minimum concentrations.

Sediments

Generally, investigations of bottom sediments in the Barents Sea reveal low levels of POPs. Sum7 PCB — the sum of seven individual indicator PCB isomers (congeners) — ranged from 0.7 to 3.5 ng/g dry weight (d.w.), and HCB ranged from 0.3 to 2.0 ng/g d.w in samples from 2003 to 2005 (Zaborska et al., 2011). A gradient from southern to northern Barents Sea had increasing levels of Sum7 PCB and quite similar levels of HCB. Sediment cores had relatively uniform concentrations of both Sum7 PCB and HCB throughout the core, which indicates strong vertical mixing of sediments in the Barents Sea (Zaborska et al., 2011).

Levels of PBDE brominated flame retardants, have been measured by IMR in surface sediments from South-Western Barents Sea and off Lofoten and Vesterålen Islands since 2009 as part of the national MAREANO (Marine AREA database for NOrwegian coastal and sea areas) program of seabed mapping. Levels for the group of 28 congeners are quite low, close to or below detection limits for most compounds, and not exceeding 20 µg/kg dry weight for the sum of compounds at any locations. Results are illustrated in Figure 4.4.11.

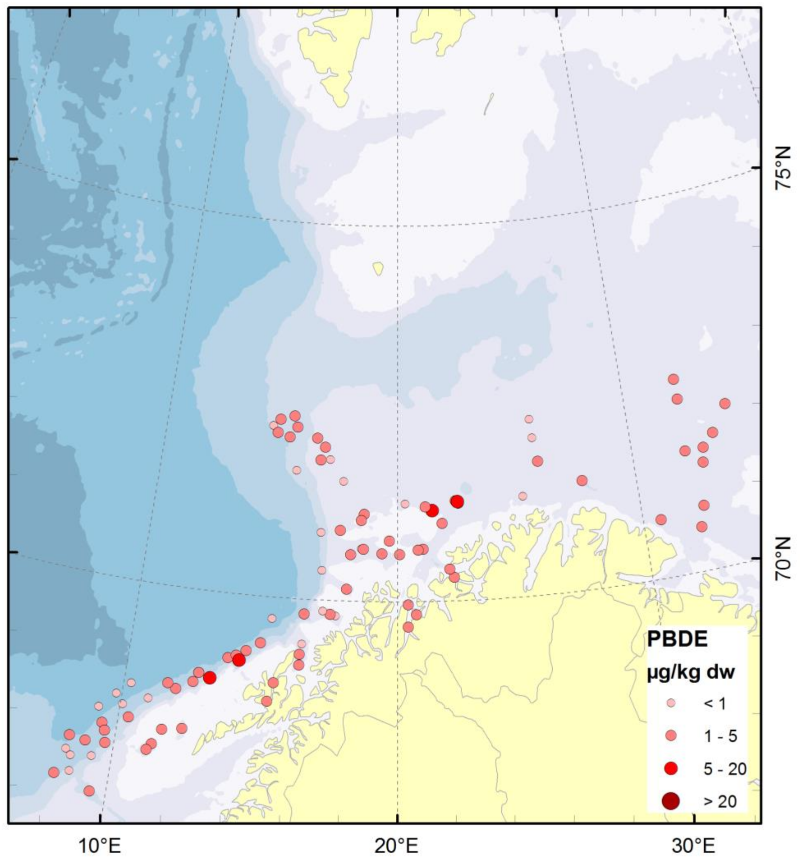


Figure 4.4.11. The concentrations of PBDE (sum of 28 congeners) in surface sediments from South-Western Barents Sea (IMR data) in µg/kg dry weight.

Marine mammals and seabirds

POPs in organisms at the top of the food web are of major concern because of the accumulating properties of POPs (See chapter 4.6.1). Levels of POPs in polar bears at Svalbard and Franz Josef Land are above the limits which effect hormone and immune systems. PCB has been found in especially high concentrations (Gabrielsen, 2007; Letcher et al., 2010). The trend across the Barents Sea shows increased levels of PCB from western populations to eastern populations, probably due to greater long-range transport of PCB substances from Europe to Svalbard and the Barents Sea area. Levels of PCB have decreased from 1990 to 2002, with a levelling out at the end of this period (Henriksen et al., 2001). Recent studies have also found newer contaminants like BFH and PFC in polar bears in the Svalbard region (Smithwick et al., 2005; Muir et al., 2006).

In herring gulls, puffins, kittiwakes, and common guillemots from northern Norway and Svalbard declining concentrations of HCB, HCH, DDT and PCBs were observed in eggs from 1983 to 2003 (Helgason et al., 2008; Helgason et al., 2012). In glaucous gulls declining plasma levels of PCB and HCB were observed from 1997 to 2006 on Bjørnøya (Bustnes et al., 2011). In contrast, increasing levels of HCBD and were observed during the same time period, 1983 to 2003, in herring gulls, puffins, and kittiwakes (Helgason et al., 2009). For PBDE, levels increased from 1983 to 1993 and decreased from 1993 to 2003, with a net increase from 1983 to 2003 for the same species (Helgason et al., 2009).

4.4.3.2 Current status and trends for heavy metals

C.F. Pettersen (NEA) and P.B. Nizzetto (NILU)

Air

Heavy metals have been part of the Norwegian national monitoring program since 1980. Monitoring heavy metals in the air was initiated at Zeppelin Observatory in 1994 and at Andøya Observatory in 2010. In 2013, annual mean concentrations of most heavy metals except mercury, nickel, and vanadium were somewhat higher at Zeppelin than observed at Andøya. This was due to individual episodes with high concentrations of heavy metals at Zeppelin during winter in 2013 (Figure 4.4.12). Episodes with increasing levels of cadmium and lead are well correlated. High levels of cadmium and lead occurred at the same time, and were not necessarily a result of common emission sources. Polluted air is often well mixed, and high levels can occur when meteorological conditions favor long-range transport. At Zeppelin, there have been significant reductions since 1994 for several elements, including arsenic, cadmium, copper, lead, nickel, and vanadium. Reductions in lead and cadmium have been 44% and 49%, respectively. Reductions of lead in the atmosphere are measured in the whole Arctic as a result of a ban on the use of leaded gasoline (AMAP, 2004). No significant trends were found for mercury at any of the sites within their measurement periods. Gaseous mercury has a longer residence time in the atmosphere than the particulate bound heavy metals, and therefore has larger potential to be transported far from emissions sources. As a consequence, mercury is a global pollutant while the other heavy metals originate more from regional pollution emissions.

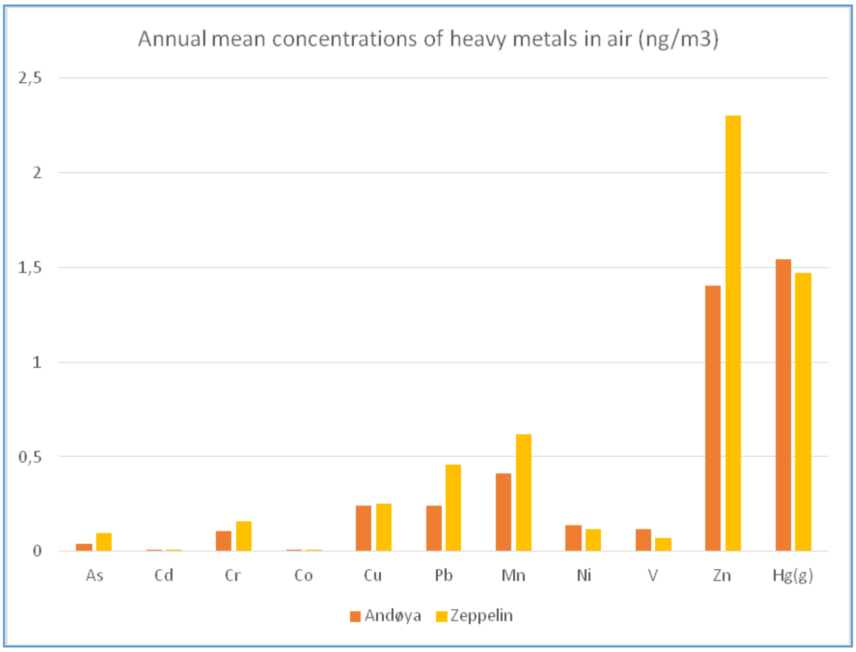


Figure 4.4.12. Annual mean concentrations of heavy metals in air (ng/m^3).

Riverine inputs of heavy metals to the Barents Sea

Results from monitoring with passive gear to estimate riverine input of heavy metals into the Barents Sea basin indicate that copper, nickel, and sulphates are the main pollutants from

Norwegian and Russian river tributaries (Figure 4.4.13). Highest concentrations were found in the Kolosjoki River, and levels were related to the direct discharge of wastewater from iron smelting operations conducted upstream. Relatively high concentrations of chromium, lead, and zinc were recorded in the Pinega River in the Arkhangelsk area (Kaste et al., 2014). Levels of nickel and copper in the rivers examined have increased throughout the 2000s. Nickel concentrations have increased in all rivers, and copper concentrations have increased in Pechanga River. In Norwegian rivers far north, the highest levels of nickel and copper were found in Pasvik River and Jakobselva (English: Jacob's River). Highest levels of chromium were found in the Mattusjåkka-, Storelva-, and Jakobselva rivers. Highest concentrations of Zn were found in Tana River and Neiden River. Highest concentrations of Pb were found in the rivers Stabburselva, Adamselva, and Jakobselva (Skarbøvik et al., 2012).

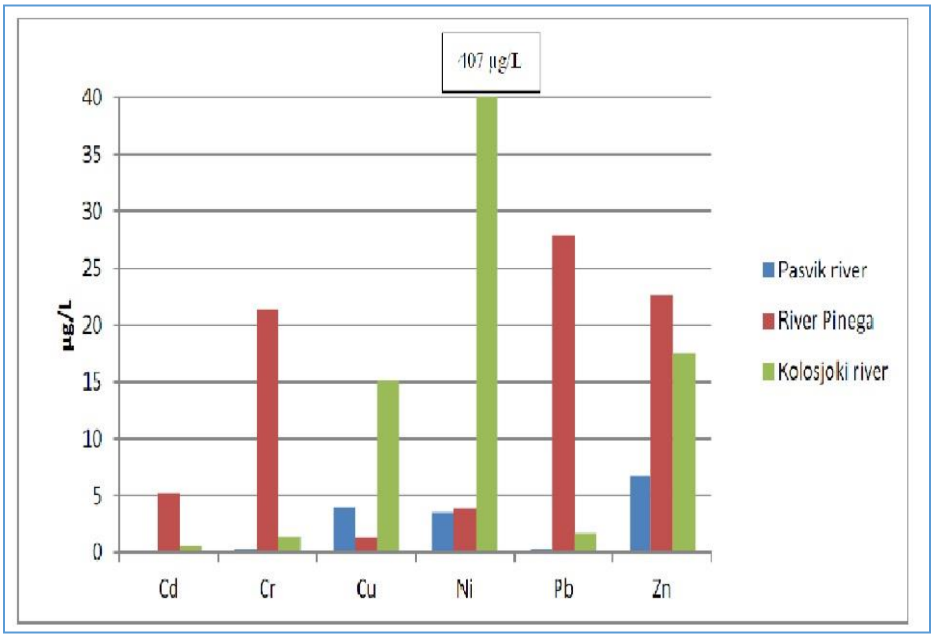


Figure 4.4.13. Results from monitoring by passive samplers in the three rivers Pasvik, Pinega and Kolosjoki. High levels of heavy metals found in river Kolosjoki are related to wastewater discharge from smelters (Kaste et al., 2014).

Heavy metals in bottom sediments

Spatial distribution of lead, copper, cadmium, nickel, chromium, iron, manganese, and zinc in sediments is characterized by a general trend of increasing concentrations from coastal areas to the deep-water part of the Central Trough (Figure 4.4.14, Table 4.4.6). Kola Bay is a high anomaly zone for heavy metal contamination.

Table 4.4.6. Concentration of heavy metals and trace elements in Barents Sea sediments, µg/g dry weight.

Location	Pb	Co	Cu	Ni	Cd	Fe	Cr	Mn	Zn	As	Hg	Sn
Central Trough	7-18	1-5	12-35	20-50	0.0-0.3	38-60	32-54	160-470	70-85	7-67	0.03-0.07	1-7
Southern part of sea	2-18	1-3	10-20	18-31	0.0-0.10	14-30	18-38	151-280	40-70	2-24	0.0-0.07	0.7-3.0
Pechora Sea	1-6	0.4-1.5	3-8	1-3	0.0-0.1	---	1.4-4.0	21-115	4-10	0.4-1.2	0.01-0.02	0.0
Coastal area and bays	5-10	3-30	4-80	12-24	0.0-0.15	9-17	18-57	128-240	26-150	1-15	0.03-0.10	1-4
**APC_0	<30	---	<35	<30	<0.25	---	<70	---	<150	<20	<0.15	---
**APC_0 = approximate permissible concentrations for uncontaminated sediments according to SFT [Norwegian Pollution Control Authority].												

Pechora Sea sediments typically have a lower level of heavy metal and trace element accumulation than other areas in the Barents Region (Figure 4.4.14). Generally a relatively low concentration of heavy metals and trace elements is typical for bottom sediments of the Barents Sea.

Geochemical estimates of sediment concentrations during 2014 in the Russian zone were made using 2008-2012 monitoring data (Figure 4.4.15). Indications were that for near-shore areas high anomalies of heavy metal contamination were influenced by water transport within the currents.

Technogenic radionuclides

Current levels of contamination in sediments from technogenic radionuclides (Cs= Cesium, Sr=Strontium, Pu=Plutonium, Sb=Antimony) are very low (Figure 4.4.16). MMBI data for 2001-2011 show that the level of ^{137}Cs ranges from 1 to 3 Bk/kg (becquerel per kilogram), and the level of ^{90}Sr ranges from 0.2 to 2.0 Bk/kg. However, in the deeper sediments of the central Barents Sea ^{137}Cs ranges from 5–8 Bk/kg and ^{239,240}Pu ranges from 0.004 to 1.33 Bk/kg. Episodically, the level of ^{125}Sb was detected at 0.4 Bk/kg in near shore areas in association with waters being transferred with the currents from industrial plants in England.

In Kola Bay, the level of ^{137}Cs in sediment is about 10 Bk/kg (on average) with a maximum value of 21.5 Bk/kg in the northern part.

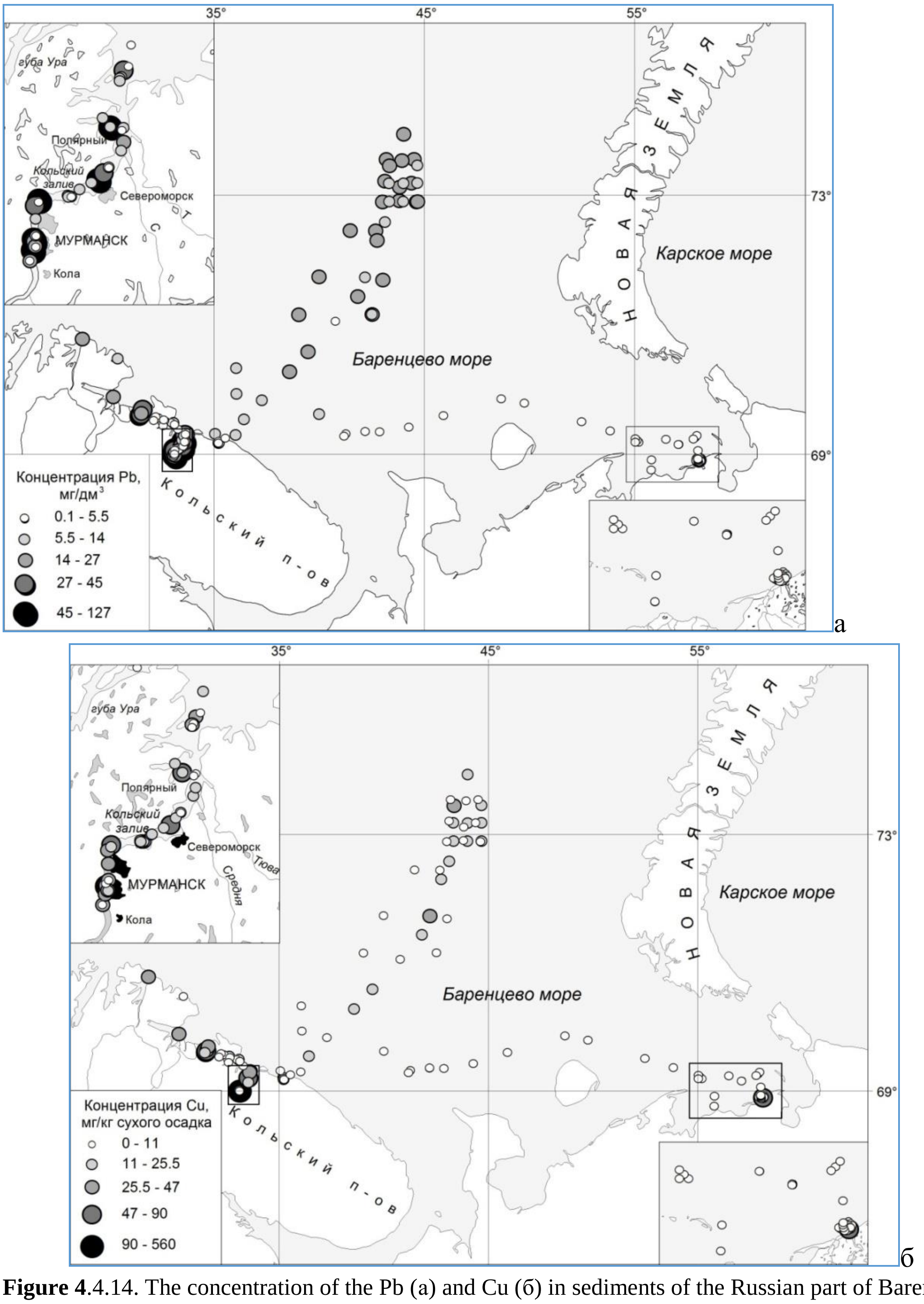


Figure 4.4.14. The concentration of the Pb (a) and Cu (б) in sediments of the Russian part of Barents sea 2008-2012 (MMBI).

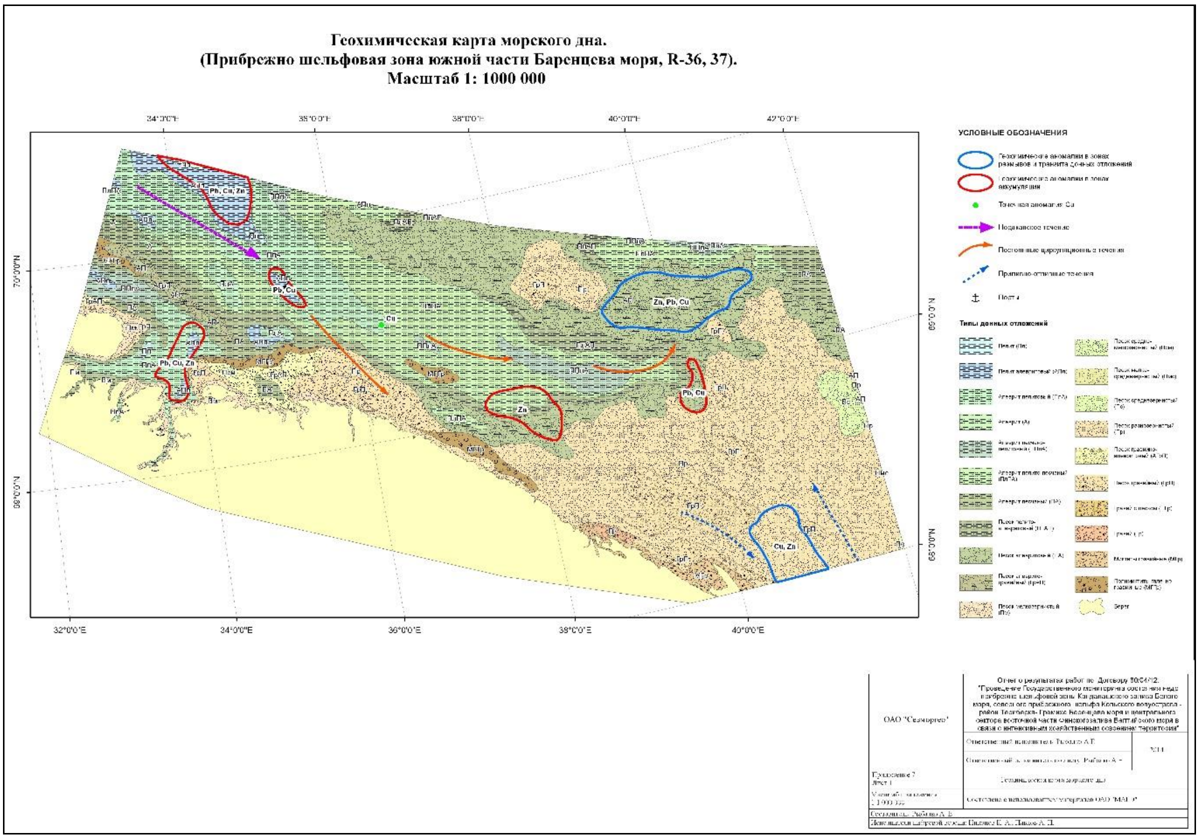


Figure 4.4.15. Geochemical map of distribution of heavy metals in near-shore of Kola Peninsula (2014).

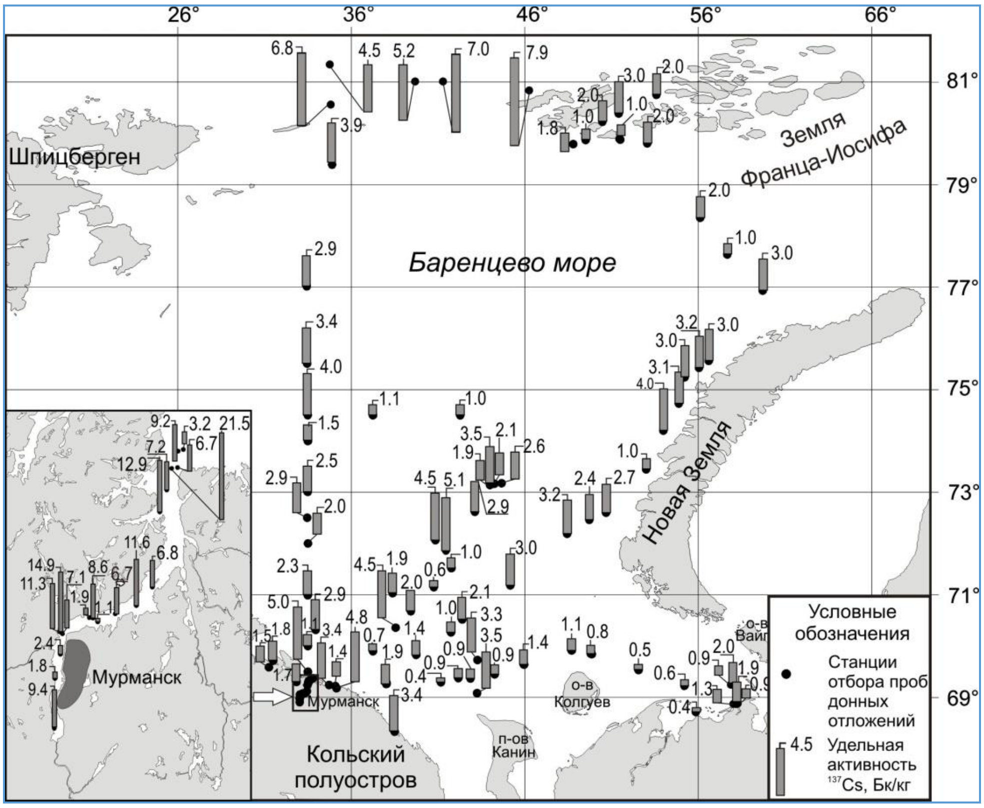


Figure 4.4.16. Radionuclide ^{137}Cs in the sediments (MMBI, 2012).

4.4.3.3 Current status and trends for hydrocarbons

C.F. Pettersen (NEA) and J. Bytingsvik (Akvaplan-niva AS)

PAH in air, riverine input, and in biota

Oil contamination might be measured as the total hydrocarbon content (THC) which includes both aliphatic and aromatic hydrocarbons (PAHs). PAHs play a significant role in the Barents Sea where hydrocarbon resources are naturally present. PAHs also originate from incomplete combustion processes of organic material, they travel long distances in the atmosphere, and are toxic to animals and humans. Hence, PAH-emission is still ongoing. Atmospheric transport has been demonstrated to be the main route for PAHs to reach pristine areas such as the Arctic. Although levels of PAH in the atmosphere still are lower in the Barents Sea area (i.e. Andenes and Ny-Ålesund) compared to the southern parts of Norway (i.e. Birkenes), the PAH-levels measured in 2013 were the highest measured since 2007 and are up to three orders of magnitude higher than levels of legacy POPs (e.g. PCBs) (Nizzetto et al., 2014). Higher levels and more local PAH-emission in the northern regions are believed due to increased industrial activity (e.g. petroleum industry), tourism, and shipping as temperatures increase.

Passive sampling of PAH concentrations in rivers that drain into the Barents Sea were found to be below 1ng/l. Concentrations of light weight PAHs were significantly lower in river Pasvik compared to rivers in southeastern parts of Norway. Smaller differences were observed for the higher molecular weight PAHs (Kaste et al., 2014).

PAH-levels in lower trophic levels have increased 10 to 30 fold the last 25 years (De Laender et al., 2011). PAH-levels were low in blue mussels (*Mytilus edulis*) sampled close to Svolvær (Nordland, Norway) and Varangerfjorden (Finnmark, Norway) in 2011. Levels found were also lower than levels measured at Greenland, Island and the Faroe Islands (Jorundsdottir et al., 2014). Dominant compounds in the Norwegian samples were phenanthrene, chrysene, and benzo(a)pyrene in samples from Svolvær and phenanthrene, fluoranthene, and pyrene in samples from Varangerfjorden. PAHs were detected in eggs of common eider, European shag, and herring gull sampled in 2012 at Røst (Nordland, Norway) (Huber et al., 2014). PAHs included in the screening were: naphtalene, acenaphtalene, acenaphtene, fluprene, phenantrhrene, antracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthrene, benzo(k)fluoranthrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, dibenz(ac/ah)anthracene, and benzo(ghi)perylene. Levels of naftalene, antracene, fluoranten, pyrene, and chrysene were above the detection limit in herring gull eggs. Only pyrene was detected in common eider, while no PAHs were detectable in the European shag. PAH-levels were highest in herring gull eggs.

Hydrocarbons in Russian waters of the Barents Sea

G.V. Iljin (PINRO) and A.E. Rybalko (SMG)

In recent years, total petroleum hydrocarbon concentrations have varied in different areas of the Russian zone of the Barents Sea within the range from 0 to 2 MPC [maximum permissible concentration] (Figure 4.4.17). The annual mean concentration of such hydrocarbons is about 0.01 mg/L (Iljin, 2015). Elevated concentrations of petroleum products, exceeding the MPC (0.05 mg/L), are generally observed in coastal areas and in bays.

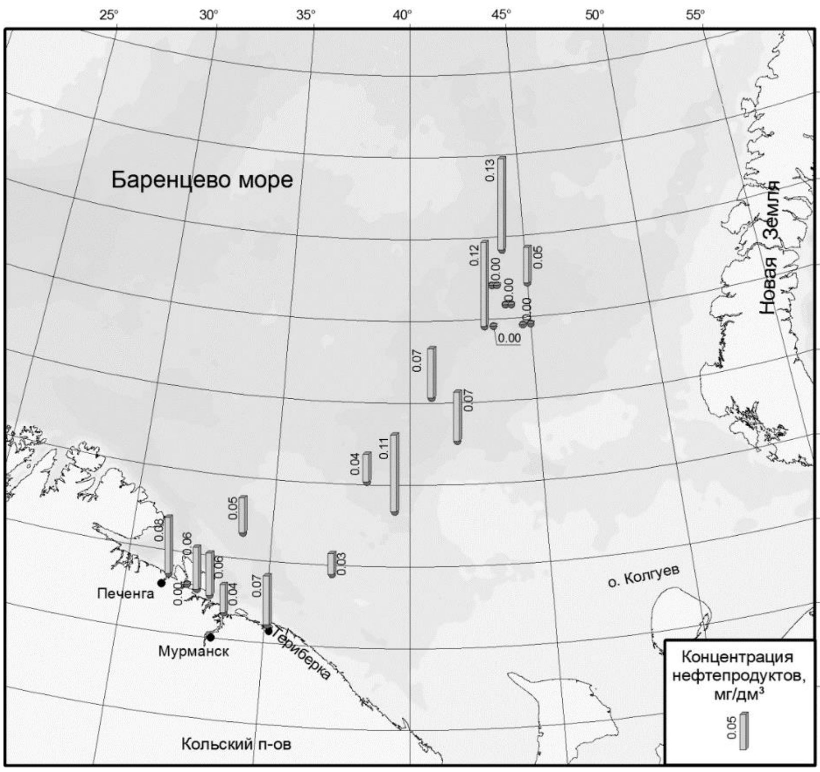


Figure 4.4.17. Distribution of hydrocarbons in the water along projected Shtocman pipeline.

Paraffins make up the majority of hydrocarbons dissolved in waters of the Barents Sea. The profile of normal paraffins is represented by C_{10} to C_{30} compounds. Their total concentration varies in the range from 1.1 to 20.0µg/L. Concentrations up to 90µg/L (Iljin, 2015) are observed in localized areas. Hydrocarbons of plant and bacterial origin (C_{20}-C_{25} alkanes) account for up to 30%-33%, and predominate in central parts of the Sea. In coastal areas, especially Motovsky- and Kola Bays, short-chain C_{12}-C_{22} alkanes predominate in the paraffin structural series. Elevated pristane/phytane isoprenoid ratios and low CPIs (carbon preference indices) are also observed in the structure of the alkanes. These parameters indicate a relatively elevated petrogenic hydrocarbon background level in areas experiencing high anthropogenic impact.

Studies investigating paraffin composition in upper layers of the water column near Franz Josef Land and the Shilling Strait [show that] the aliphatic hydrocarbon profile is limited to normal C_{15}–C_{24} paraffins. C_{18} (28%) and C_{23} (19%) alkanes dominate. Hypothetically, the observed aliphatic hydrocarbon background in waters surrounding the archipelago is not associated with petroleum contamination, but rather is created by metabolites of organisms of the marine biota. The total concentration of normal paraffins is not more than 1.5µg/L — two orders of magnitude lower than in commercially developed southern areas of the Sea (Iljin, 2009; Iljin et al., 2011).

The total concentration of polyaromatic hydrocarbons (PAHs) in the Barents Sea is low, and PAH constituent composition is depleted. In the southern part of the Sea, PAH concentration varies from 12 to 80ng/L (Figure 4.4.18). Concentrations of perylene, pyrene, phenanthrene, fluorene, fluoranthene, and benz[*b*,*k*]fluoranthene have been reliably determined. Concentrations of carcinogenic polyaromatic compounds, including benz[*a*]pyrene, are below the detection threshold. Arenes, perylene, and benz[*b*,*k*]fluoranthene dominate PAH composition; these are indicators of anthropogenic emissions associated with pyrolysis of organic fuel. But the major role in transport of PAHs in the open sea is probably played by atmospheric deposition (Shevchenko, 2009).

An increase in PAH concentration, associated with anthropogenic impact, occurs in coastal areas. Concentrations up to 80-90ng/L have been observed in the western margin of the Sea. In the southeastern part (Pechora Sea), PAH concentration is reduced to 15-67ng/L (Iljin, 2015).

In offshore areas, PAH concentration appreciably increases in bottom layers of the water column near oil and gas fields. In deep-water areas of Central Trough, where the Shtokman gas condensate field is located, PAH concentration can be 260-330ng/L (Iljin, 2015). In shallow waters of the Pechora Sea near Prirazlomnoye field, total PAH concentration in the bottom layer increases up to 120ng/L.

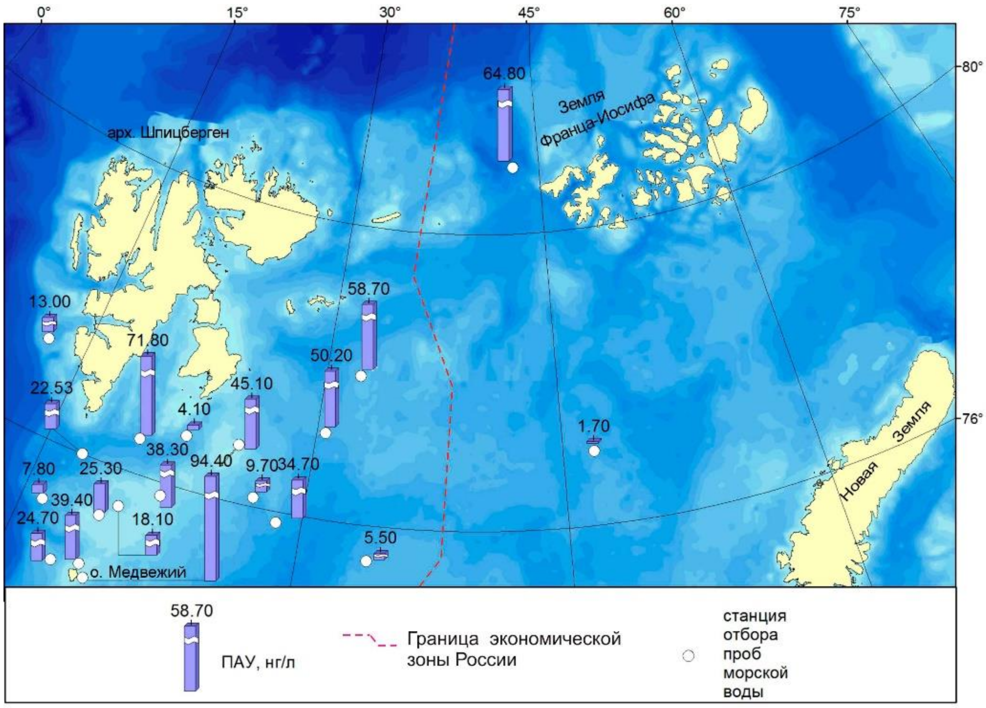


Figure 4.4.18. Distribution of PAH in waters of the Barents Sea.

Pesticides

Metabolites of DDT are the most widely distributed pesticides in the Barents Sea. Metabolites *p′,p*-DDE, *p′,p*-DDD, *o′,p*-DDD, *o′,p*-DDT, and *p′,p*-DDT are observed in the open sea. Total concentrations are low, and vary within the range from 1.8 to 3.2ng/L, and correspond to relatively clean waters. Elevated concentrations have been recorded occasionally in localized Western Murman coastal areas and in frontal zones.

In bottom layers, DDT concentrations are generally reduced to trace amounts, while in Kola and Motovsky Bay area they may be about 0.2ng/L. Obviously, DDT enters the Barents Sea from relatively remote sources, with Atlantic Ocean currents and with the Norwegian Coastal Current (Iljin, 2015).

In Pechora Sea, DDT metabolites also arrive with waters of the currents. Moving eastward, their total concentration is reduced to 0.05-0.50ng/L. The constituent composition of the metabolites is even more depleted (Iljin, 2015).

Another widely distributed pesticide, hexachlorocyclohexane (HCCH), is also detected over the entire southern part of the Sea, but is present at lower concentrations than DDT. Just as with DDT, Atlantic waters periodically transport the product HCCH relatively untransformed from the Norwegian Sea. The coastal area also shows a trend of decreasing concentrations eastward from the western periphery of the Barents Sea. The total HCCH concentration decreases from Varanger Fjord to Cape Svyatoy Nos, from 1.7 to 0.7ng/L (2003 Status Report). In coastal waters of the Pechora Sea, all the isomers are again detected: α-, β-, and γ-HCCH, although not in insignificant amounts. Proportions of the isomers vary: the α-HCCH concentration varies from 0.25 to 1.0ng/L; γ-HCCH, from 0.05 to 0.4ng/L; β-HCCH, from 0.05 to 0.6ng/L.

Persistent organochlorine compounds are also observed in the northern periphery of the Sea. DDT concentrations are as high as 0.7ng/L; HCCH, about 0.6ng/L; and the anthropogenic pollutant PCB, 1.3ng/L. Concentration of these persistent organochlorine compounds (OCCs) are below the permissible limits for fisheries.

Polychlorinated biphenyls (PCBs)

PHBs (polyhalogenated biphenyls) are found at low concentrations in the Barents Sea. They are detected in localized areas, associated with frontal zones at branches of warm Barents Sea currents, and also onshore. The concentration of these compounds is about 4.5ng/L on the average; which is much lower than the MPC level (10ng/L). In bottom layers of the open sea, polychlorinated biphenyls are observed in some areas; their concentrations are significantly lower than at the surface and do not exceed 0.5ng/L. The PCB concentration at the bottom may increase in some coastal areas up to 0.7-0.9ng/L (Iljin, 2015). At the same time, previously in the Zapadnaya Litsa Bay, anomalously high PCB concentrations were detected in areas where naval vessels were based, which is associated with periodic painting of ships and high PCB content in industrial paint.

The PCB concentration decreases progressing eastward. Waters of Motovsky Bay bordering Norway can contain about 2.5ng/L in the surface layer and about 1.2ng/L in the bottom layer. Contamination in the Pechora Sea with polychlorobiphenyls is estimated at 0.05-1.8ng/L (Iljin, 2015).

Generally, a latitudinal concentration gradient is seen in the region for organochlorine compounds, which is probably determined by the entry of Atlantic waters.

Hydrocarbons in bottom sediments

S. Boitsov (IMR)

Polycyclic aromatic hydrocarbons (PAHs) play a significant role in the Barents Sea where hydrocarbon resources are naturally present. PAHs found in marine sediments may be due to natural processes such as erosion of coal-bearing bedrock at Svalbard or seepages of oil and gas from the seabed. Anthropogenic sources of hydrocarbons play a lesser role in the Barents Sea.

In most areas, the background levels of PAHs in sediments are low, and have been at 400-500 µg/kg dry weight on average for a sum of 48 PAHs throughout the western Barents Sea. The levels are highest closer to Svalbard, whereas the sediments from the shelf areas of southern Barents Sea mapped under the MAREANO program had very low levels of PAH, mostly < 300 µg/kg dry weight for the same group of compounds. The latest results from the previously disputed area along the Norwegian-Russian border in central Barents Sea, obtained in 2013, indicate similarly low PAH levels.

Accumulation of petroleum products in bottom sediments in open areas of the Barents Sea is quite patchy, and concentrations may vary from trace amounts up to 80µg/g dry weight. Highest concentrations are observed in coastal sediments and in sediments of the Central Trough, where accumulation of the finely dispersed fraction of residues occurs. The range of hydrocarbon concentration in different morphological zones of the sea is shown in Table 4.4.7. In Murman coastal sediments, especially close to Kola- and Motovsky Bay, the concentration of petroleum products increases. Areas of petroleum product accumulation ranging from 120 to 700µg/g dry weight have been observed during different years in this area of the coast.

The structural composition of the paraffinic hydrocarbons in bottom sediments is broader than in aquatic environments (Table 4.4.7). Dominant paraffins are C_{12}–C_{17} and C_{18}–C_{24} aliphatic compounds.

Short-chain C_{10}–C_{14} compounds are observed practically over the entire Barents Sea. But, these light compounds are more typical in bottom sediments of the Central Trough, which may be due to elimination of light hydrocarbons from the sedimentary cover.

Bottom sediments near Franz Josef Land have low petroleum hydrocarbon concentrations: 40-160mg/kg dry weight. This is 1-2 orders of magnitude lower than in southern areas. To evaluate the indicated quantities, and set standards for the approximate permissible concentration of total petroleum products in uncontaminated marine sediments, we can use the standards of the Norwegian Pollution Control Authority (SFT): 50 mg/g dry weight (Molvaer et al., 1997).

In most samples of bottom sediment taken during 2014 in Teriberka Bay (SMG), the concentration of petroleum products was low and did not exceed the background level for contamination by petroleum products according to the Norwegian scale, except for a station located in upper Dolgaya Bay (Figure 4.4.19).

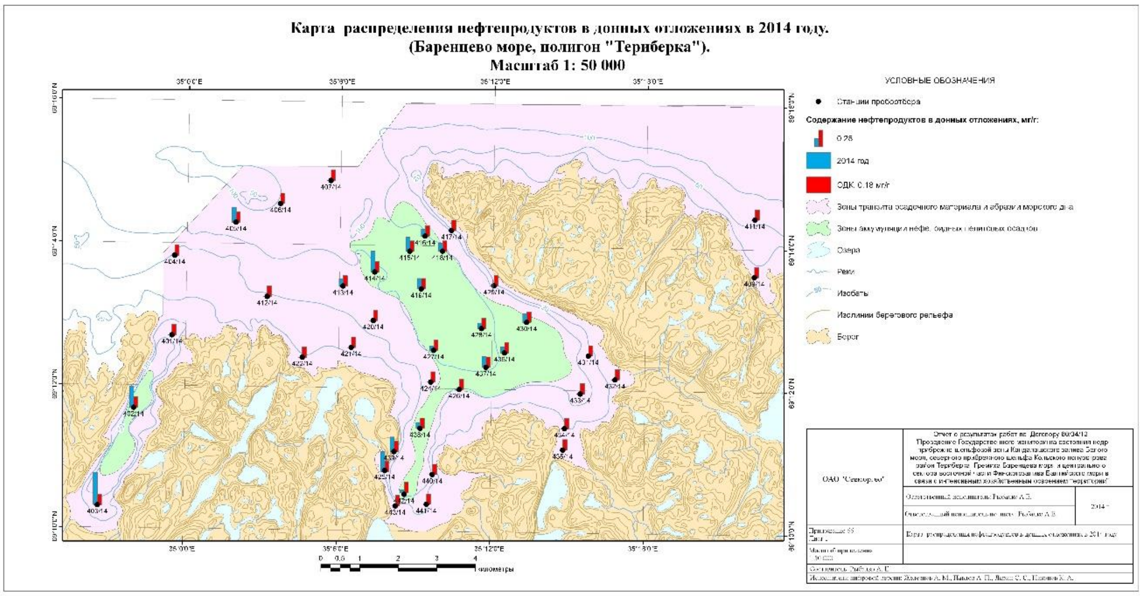


Figure 4.4.19. Distribution of total hydrocarbon content (THC) in Teriberka Bay sediments (2014)

Although PAH distribution in bottom sediments is not uniform over the entire southern part of the Barents Sea (from 20 to 400ng/g dry weight), maximum PAH accumulation occurs in sediments of the Central Trough and bays along the Murman Coast (Table 4.4.7).

Table 4.4.7. Concentration of petroleum products, PAHs, and indices of paraffin composition in bottom sediments in the southern Barents Sea.

Parameters	Location			
	Central Trough	Murman Shoal/Rybachya Bank	Coastal area	Bays
Σ Petroleum products, μg/g dry weight	0.0–80.0	0.0–60.0	10–700	8–120
Σ n-C_{10}-C_{34}, μg/g dry weight	1.7–2.0	1.6–2.3	1.6–20.9	2.0–8.0
CPI: $\frac{\Sigma\Sigma n\text{-}C_{odd}}{\Sigma\, n\text{-}C_{even}}$	0.69–0.97	0.41–1.11	0.53–0.93	1.2
index $\frac{n\text{-}C_{12}\text{-}C_{22}}{n\text{-}C_{23}\text{-}C_{34}}$	1.24–2.16	0.14–6.73	1.16–3.61	2.5
Σ PAHs, ng/g dry weight	20–399	20–188	38–197	25–2060

Pyrogenic compounds predominate in sediments: pyrene, benzanthracenes and dibenzanthracenes, fluoranthene, etc., which have carcinogenic properties. The benz[*a*]pyrene concentration varies from 0 to 14ng/g dry weight. Sediments of the Central Trough typically have the maximum level of carcinogen accumulation.

In open areas of the Sea, accumulation of PAHs of petrogenic origin is typical: chrysene and phenanthrene. These arenes result from the metamorphosis of organic matter, and enter the environment as bottom sediments erode.

On the coast of the Pechora Sea in the east, total PAH concentration is significantly lower than in central and western parts of the Sea, and varies from 5 to 80ng/g dry weight. It is slightly elevated in oil and gas field areas within the Pechora Sea basin; major arenes found among the PAHs are naphthalene (5-40ng/g dry weight) and fluoranthene (0.2-0.4ng/g dry weight), which are compounds of petrogenic and anthropogenic genesis. The concentration of benz[*a*]pyrene is very low: from 0.0 to 5.2ng/g dry weight.

In western coastal areas, the PAH profile is significantly broader. Near the mouth of Kola Bay, in Motovsky Bay, and in Varanger Fjord, major aromatic compounds in the sediments become compounds of petrogenic genesis: naphthalene and fluoranthene, indicating long-term anthropogenic impacts. Total PAH concentration here is generally low: from 7 to 147ng/g dry weight, many times lower than the "contamination" threshold according to the SFT classification. A trend of increasing concentrations from Varanger Fjord to Kola Bay has been observed. Sediments in Pechenga Bay and Ura Bay — the southern and central parts ("bends") of Kola Bay — are significantly more heavily contaminated than open areas of Varanger Fjord and Kola Bay.

The PAH concentration in sediments of Franz-Victoria Trough is low and typical for central parts of the Barents Sea. However, variability in the concentration level is considerable: ranging from 200 to 600ng/g dry weight. Analysis of the PAH composition shows relatively high concentration of phenanthrene, naphthalene, and its methylated homologs. Potential sources of these compounds include: erosion and abrasion of rocks on surrounding archipelagos containing coal; airborne transport of dusty material; and invasion of light PAHs (naphthalenes) from sedimentary cover (Figure 4.4.20).

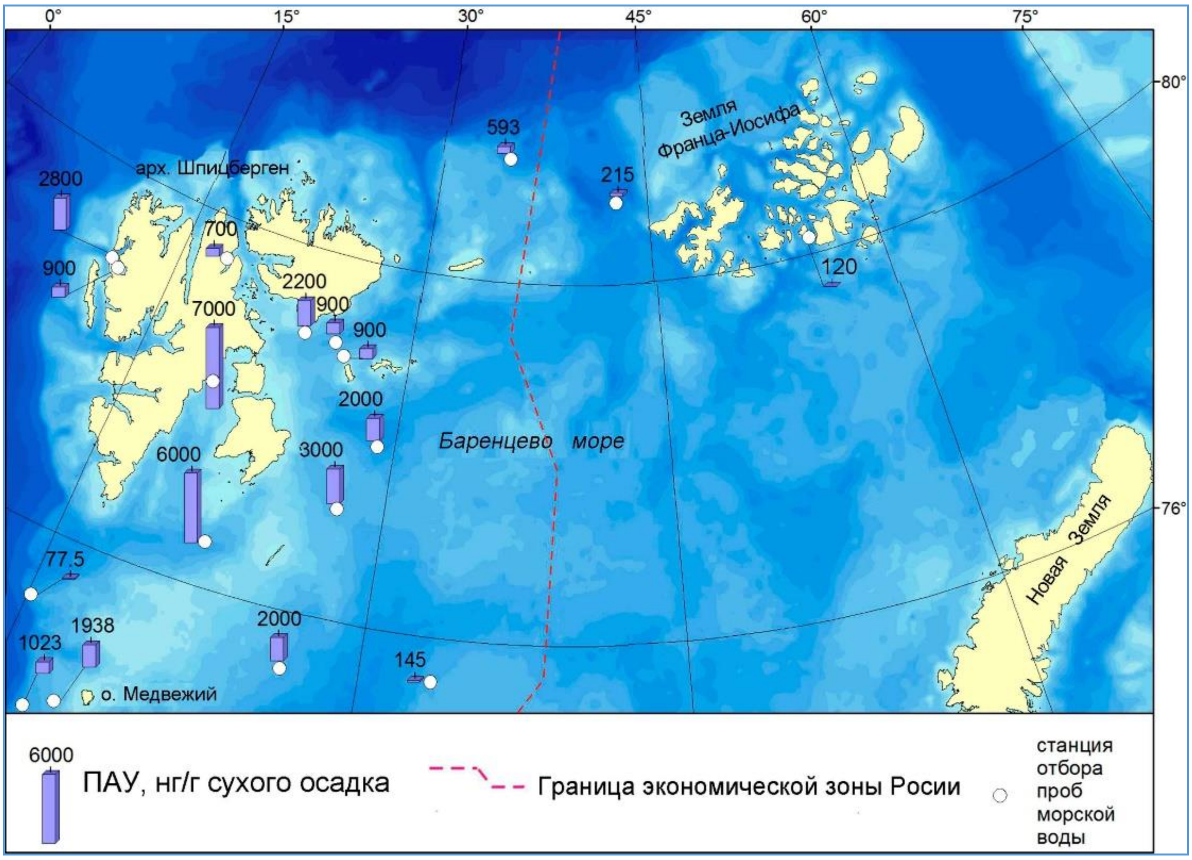


Figure 4.4.20. Distribution of PAH in the sediments of the Barents Sea.

PAHs found in marine sediments may be due to natural processes such as erosion of coal-bearing bedrock at Svalbard or seepage of oil and gas from the seabed. Offshore environmental monitoring indicates that differences in physical characteristics of sediments correlate to natural background levels of chemical substances. The highest concentrations of THC and heavy metals are found at some regional monitoring stations where sediments have high content of pelite and total organic matter (TOM).

Gas production at Snøhvit began in 2007; this was the only producing field in 2011 in the Norwegian part of the Barents Sea. Drilling has not occurred between 2007 and 2010, and emissions are insignificant. Levels of THC in sediments close to Fish, Salina, Ververis, and Caurus vary between 4 – 10mg/kg. Highest levels of THC were found at Snøhvit and Norvarg, with maximum concentrations between 13.4mg/kg and 13.9mg/kg (Mannvik et al., 2011).

Polychlorobiphenyls (PHBs)

Level of accumulation of polychlorobiphenyls (PHBs) in bottom sediments is typically very low. In open areas of the Sea, 35% of the tests for concentration of these compounds were below the detection threshold. In areas where these compounds accumulate, the concentration (on average) is 0.3ng/g dry weight. But, in sediments of the Central Trough and in coastal sediments, PCB concentrations are relatively elevated, up to 1.0-1.5ng/g dry weight and 2.5ng/g, respectively.

In sediments of the Pechora Sea, PCB concentration is practically the same as in southern and central areas of the Sea, and range from 0.05 to 2.3ng/g dry weight.

In the coastal area, a trend of westward increase in PCB concentrations has been observed. In areas of Motovsky Bay, more than 2.5ng/g PCB has accumulated in sediments. In sediments of Varanger Fjord, PCB concentration increases in some places up to 4.0ng/g dry weight. Highest concentrations of this anthropogenic pollutant can be observed in sediments of Pechenga Bay (4-19ng/g dry weight), in connection with its active use by the navy for cleaning. In general, sediments are classified as "uncontaminated" by PCBs (ΣPCBs < 5µg/g dry weight according to the SFT classification).

Persistent organic pollutants (POPs)

Organochlorine pesticides enter the Barents Sea and are transported within it mainly with warm Atlantic currents and with atmospheric aerosols. Total accumulation of such pesticides in Barents Sea sediments is lower by far than the approximate level even for uncontaminated sediments (<500ng/g dry weight according to SFT). Total DDT concentration varies from 0.4 to 15.8ng/g dry weight, and is 3.3ng/g on average; while total HCCH concentration in sediments of the open sea ranges from 1.5 to 5.2ng/g, and is 3.1ng/g on average.

Maximum DDT concentrations are typical for sediments in the Central Trough. The maximum HCCH concentration gravitates toward the Murman Shoal area.

In coastal sediments, DDT and HCCH concentrations are reduced compared with open areas, where a trend toward decreased concentrations from west to east is observed. Therefore, in sediments of Varanger Fjord, DDT concentration is about 1.5ng/g dry weight, and HCCH concentrations are not much higher than in sediments of Motovsky Bay (≈0.5ng/g dry weight).

In sediments of Franz-Victoria Trough, concentrations of the pesticides DDT (0-7.5ng/g dry weight) and HCCH (1-9ng/g dry weight) are relatively low and uniform, while the DDT/HCCH ratio is 10:1 on average. For other areas — including the southern tip of Spitzbergen, the coastal area of Franz Josef Land, the Perseus Trough, and the Novaya Zemlya Bank — other ratios of organochlorine pesticides are typical; this reflects spatial variability in the effects of oceanographic factors in redistribution of pollutants in marine environments (Figure 4.4.21).

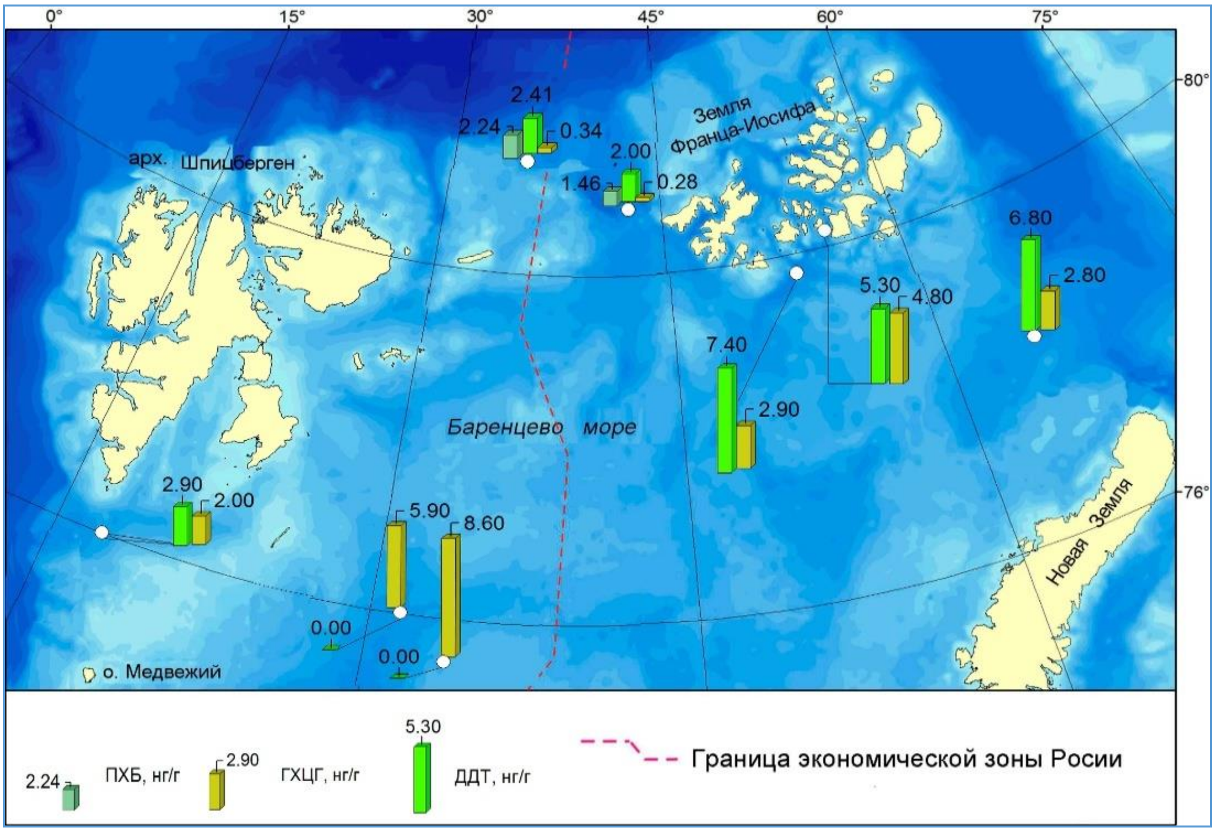


Figure 4.4.21. Distribution of POPs in the sediment of the Barents Sea.

4.4.3.4 Current status and trends for radioactive substances

A. Nalbandyan (NRPA)

The issue of present and potential radioactive contamination in the marine environment has received considerable attention in Norway. The Norwegian marine monitoring programme (RAME) focuses on monitoring of radioactivity both in coastal areas and in the open sea. This programme also includes monitoring of discharges from Norwegian sources and collection of discharge data relevant for the long-range transport of radionuclides from various sources (NRPA, 2011).

Overall, the activity concentrations of such radionuclides as ^{99}Tc, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am and ^{226} Ra in the Barents Sea are similar or slightly lower than have been observed in recent years. Presently, a general tendency to decrease is indicated for all the radionuclides. This can be explained by reduced discharges, radioactive decay and other processes such as sedimentation and dilution (NRPA, 2011).

Radioactivity in sea water and sediments

The main source of ^{99}Tc in Norwegian waters is liquid discharge from the reprocessing plant at Sellafield in the United Kingdom. From the Irish Sea, ^{99}Tc is transported by ocean currents to the North Sea and via the Norwegian Coastal Current up to the Barents Sea. The activity concentration of ^{99}Tc in the Barents Sea in 2008 and 2009 ranged from 0.03 to 0.44 Bq m^{-3}.

The highest concentrations were found in coastal water. The activity concentrations found in the North Sea and the Barents Sea are generally lower than those observed in 2002, 2003 and 2005 (NRPA, 2005; NRPA, 2007). The reason for this is the reduced discharge of ^{99}Tc from Sellafield (Figure 4.4.23a).

Strontium-90 is a fission product with a physical half-life of 29 years. Similar to ^{99}Tc, ^{90}Sr is a conservatively behaving element in the marine environment. The main sources of ^{90}Sr in the Barents Sea are discharge of liquid waste from reprocessing plants (mainly Sellafield), fallout from atmospheric nuclear weapons tests conducted mainly in the 1950s and 1960s and outflow of water from the Baltic Sea. In the Barents Sea the activity concentration in surface water ranged from 0.7 Bq m^{-3} to 1.5 Bq m^{-3}. Results show that the activity concentration of ^{90}Sr in sea water is slowly decreasing. One explanation for this is the reduced discharges from Sellafield over the last 10 years (Figure 4.4.23b).

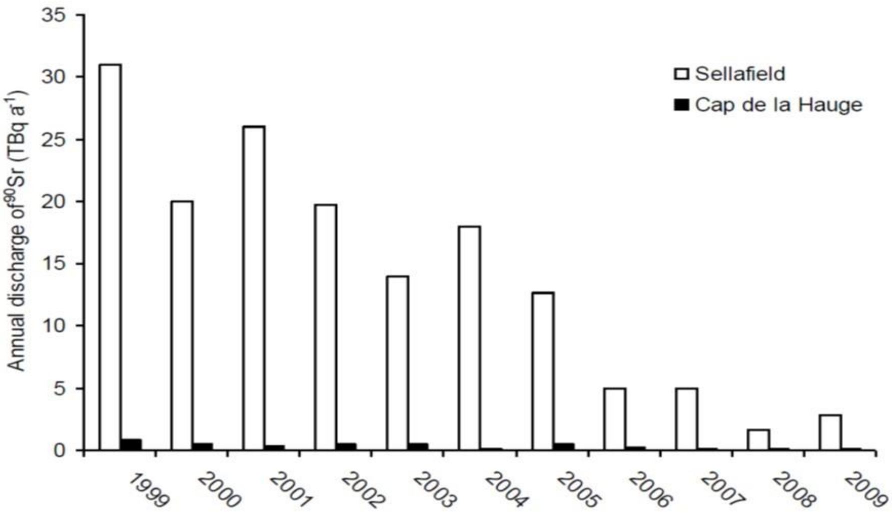
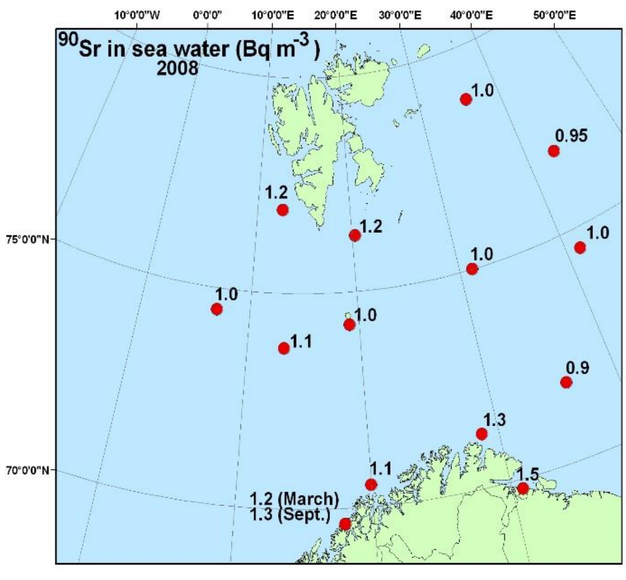


Figure 4.4.22. Annual liquid discharge of ^{90}Sr from Sellafield and Cap de la Hague in the period 1999 to 2009 (data from OSPAR, NRPA, 2011).



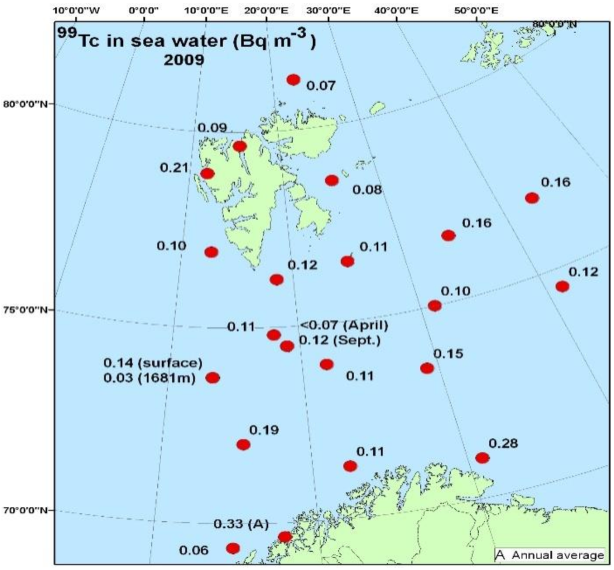


Figure 4.4.23 a&b. Activity concentration (Bq m^{-3}) of ^{99}Tc (a) in surface water and ^{90}Sr (b) in sea water samples collected in the Barents Sea in 2008 and 2009, respectively (NRPA, 2011).

Caesium-137 is a fission product with a half-life of 30 years. The main sources of ^{137}Cs in the Barents Sea are fallout from atmospheric nuclear weapons tests in the 1950s and 60s, outflowing water from the Baltic Sea and ^{137}Cs remobilised from the Irish Sea sediments. Runoff from land, from the areas with the highest Chernobyl fallout can also contribute locally in coastal water. Like ^{99}Tc and ^{90}Sr, ^{137}Cs is also a conservatively behaving radionuclide in sea water. Observed levels of ^{137}Cs in surface water in the Barents Sea in 2009 showed an activity concentration in the range from 1.5 to 2.3 Bq m^{-3}. This is generally similar or lower than the activity concentrations observed in the same area in the period 2002 to 2006. Cs-137 has also been analysed in surface sediments (upper 2 cm layer) from the Barents Sea and showed activity concentrations between 0.8 and 7.0 Bq kg-1.in dry weight (d.w.) (Figure 4.4.24).

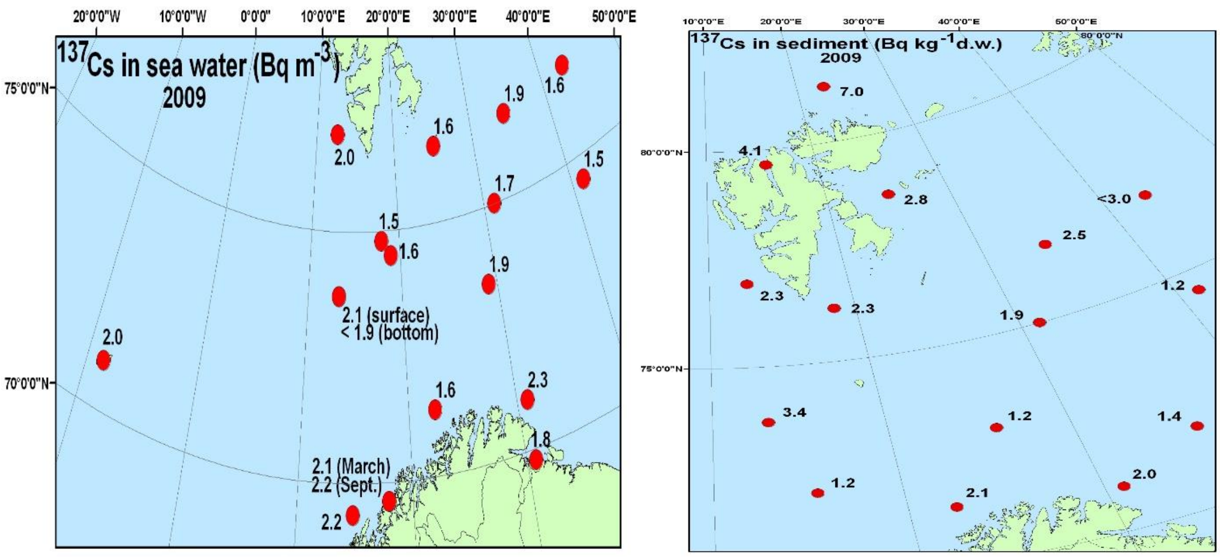


Figure 4.4.24. Activity concentration (Bq m^{-3}) of ^{137}Cs in surface water (a) and in sediment (Bq kg $^{-1}$ d.w.)(b) samples collected in the Barents Sea in 2009 (NRPA, 2011).

Plutonium-239 (a half-life of 24 110 y) and ^{240}Pu (a half-life of 6 563 y) belong to the transuranium elements. The behavior of plutonium in the marine environment is complex due to its different possible oxidation states. The main sources of $^{239+240}Pu$ in the Northern Norwegian marine waters are the global fallout from atmospheric nuclear weapons tests in the 1950s and 1960s and remobilised plutonium from the Irish Sea sediments. Observed levels of $^{239+240}Pu$ in the Barents Sea in 2008 and 2009 ranged from 1.4 to 12.4 mBq m^{-3} (Figure 4.4.25a). The activity concentrations of $^{239+240}Pu$ are similar to those found in 2002 and 2005 (NRPA, 2011).

Americium-241 belongs to the transuranium elements and has a physical half-life of 432 years. Main sources of ^{241}Am in the environment are fallout of ^{241}Pu from nuclear weapon tests in the 1950s and 1960s and the discharge of ^{241}Am and ^{241}Pu from reprocessing plants. The measured activity concentrations of ^{241}Am in the Barents Sea in 2008 and 2009 ranged from 1.0 to 9.0 mBq m^{-3} (Figure 4.4.25b). The observed levels of ^{241}Am are similar to those found in 2002 and 2005 (NRPA, 2011).

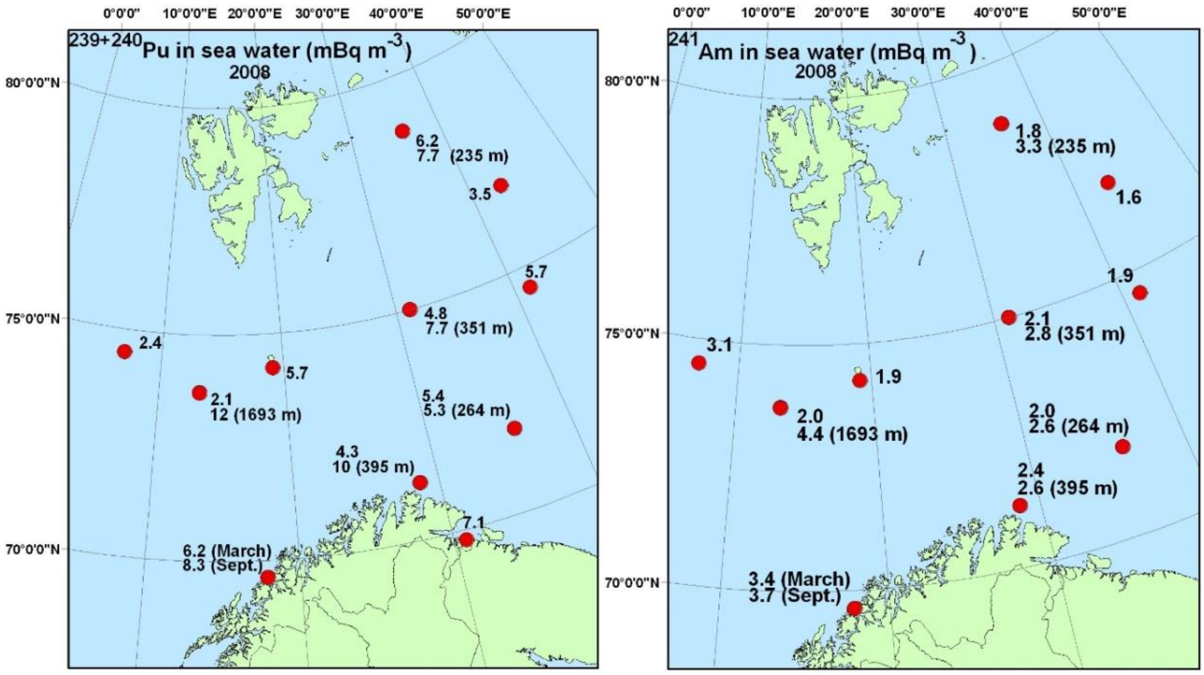


Figure 4.4.25 a&b. Activity concentration (mBq m^{-3}) of $^{239+240}Pu$ in surface water and (a) and ^{241}Am in sea water (b) samples from the Barents Sea in 2008 (NRPA, 2011).

Radium-226 is a naturally occurring radionuclide with a physical half-life of 1 600 years. In the marine environment ^{226}Ra is naturally supplied from both the sediments and by river water to the oceans. The activity concentrations of ^{226}Ra observed in the Barents Sea in 2009 ranged from 0.9 to 2.4 Bq m^{-3} (Figure 4.4.26). This is similar to those found in 2005 in the same area (NRPA, 2006; NRPA, 2011).

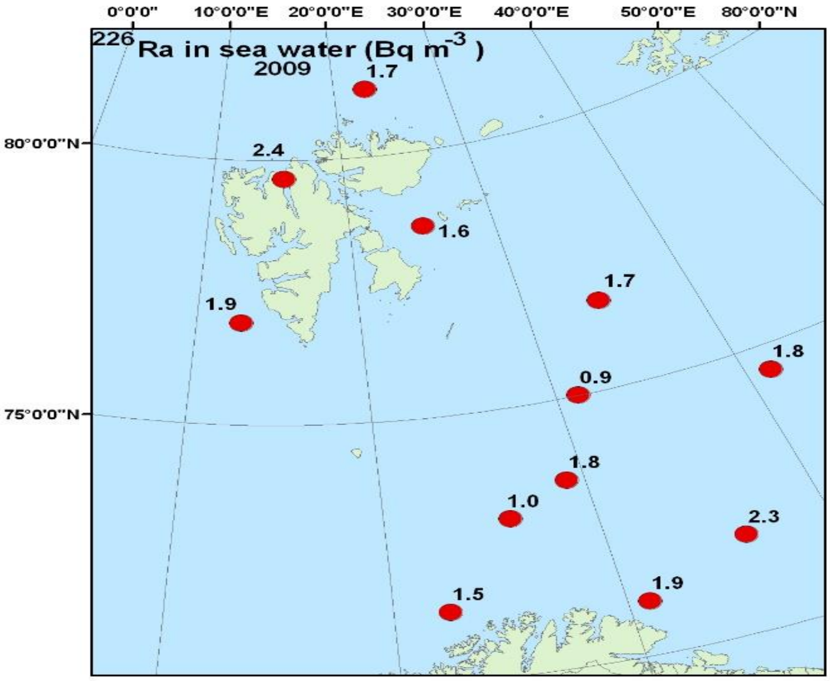


Figure 4.4.26. Activity concentration (Bq m^{-3}) of ^{226}Ra in Barents Sea surface water in 2009 (NRPA, 2011).

Radioactivity in biota

^{99}Tc, ^{137}Cs and $^{239+240}Pu$ in seaweed

Seaweed is a useful bioindicator for accumulation of radioactive substances in the marine environment. It has a high ability to concentrate radionuclides from the sea water and is easy accessible in most coastal areas. *Fucus vesiculosus* has been widely used as a bioindicator for ^{137}Cs and ^{99}Tc. The accumulation of ^{137}Cs in brown algae is, however, not as pronounced as for ^{99}Tc. The uptake of ^{137}Cs also depends on the salinity of the surrounding sea water, with higher uptake at lower salinities (Carlsson and Erlandsson, 1991).

The seaweed species (*Fucus vesiculosus*) — collected at the permanent coastal stations along the Norwegian coastline in 2008 and 2009 — showed an activity concentration of ^{99}Tc in range from 35 to 115 Bq kg^{-1} (d.w.). For most stations the levels were lower in 2008 and 2009 compared to observed levels in the period 2002 - 2007. The monitoring results showed that the levels of ^{99}Tc in seaweed have decreased at most sampling sites due to the reduced discharge of ^{99}Tc from Sellafield (NRPA, 2011).

The activity concentration of ^{137}Cs in *Fucus vesiculosus* sampled at the coastal stations in 2008 and 2009 was in the range from < 0.2 to 3.3 Bq kg^{-1} (d.w.). Data from monthly monitoring at Utsira indicates that the levels of ^{137}Cs in seaweed are slowly decreasing. One can also see a slowly decreasing trend in the activity concentration of $^{239+240}Pu$ in the seaweed samples collected at Utsira in period from 1980 to 2009 (NRPA, 2011).

^{137}Cs in fish, molluscs and crustaceans

Different types of fish and other commercially important species have been sampled in the Barents Sea since 1990s. The activity concentration of ^{137}Cs in cod caught in two areas of the

Barents Sea in 1990s was below 1 Bq kg^{-1} in wet weight (w.w.), samples collected in recent years (2008 and 2009) showed levels below 0.5 Bq kg^{-1} (w.w.). Overall, the monitoring results of fish for period 1992-2009 showed a slightly decreasing trend of ^{137}Cs concentration in fish species from the Barents Sea and indicated low activity concentrations in general. Cs-137 activity concentrations in crustaceans and mollusks caught in Norwegian marine waters in 2008 and 2009 were below1.5 Bq kg^{-1} (w.w.).

4.4.4 Maritime transport

O. Korneev (SMG) and A. Bambulyak (Akvaplan-niva)

Transport of crude oil and other petroleum products from ports and terminals in Northwest Russia through the Barents Sea has been increasing over the last decade. In 2002, about 5 million tons of Russian oil was exported along the North-Norwegian coastline, in 2004, the volume reached almost 12 million tons, but dropped the following year; during 2005 to 2013, levels of export ranged between 9 and 12 million tons per year. In a five-ten year perspective, the total available capacity from Russian arctic oil export terminals can reach the level of 100 million tons/year (Bambulyak and Frantzen, 2015b). Therefore, the risk of large accidents with oil tankers will increase in the years to come, unless considerable measures are imposed to reduce such risk (ICES AFWG, 2014).

4.4.4.1 Operational discharge (oil, contaminated water, ballast water)

As mentioned in chapter 4.4.2.2, no major impacts have been documented from operational discharges of oil and chemicals from anti-fouling systems related to ship transport.

Day-to-day impacts of shipping on the environment are caused by ordinary operational discharges. Routine discharges that have greatest impact on the Barents Sea are operational oil discharges and release of organotin compounds from anti-fouling systems.

Steady pressure on the marine environment caused by oil pollution will have negative impacts, particularly on seabird populations. However, it has not been possible to quantify impacts in the Barents Sea.

To protect ships against corrosion, zinc anodes are used in addition to special paints. If zinc anodes are used in ballast tanks, zinc content in the water discharged may exceed the tolerance limits of fish eggs and larvae by a factor of 10 to 100. This may have local impacts in areas where ballast water is discharged. Thus far, such impacts have not been documented.

Impacts from emissions to air

Maritime transport contributes to air emissions of CO_2, NO_X, non-methane volatile organic compounds (NMVOC), methane, SO_2, and soot (black carbon). Impacts from these emissions are discussed in chapter 4.4.3 – Pollution.

4.4.4.2 Collisions with marine organisms

Vessel collisions or ship strikes may result in death or serious injury of marine mammals, i.e., massive trauma, hemorrhaging, broken bones, and propeller wounds. Collisions occur mainly with large whale species, small cetaceans (i.e., dolphins, narwhal, and beluga), marine turtles, and sirenians, i.e., manatees, and dugongs (Arctic Council, 2009).

The most vulnerable species are inevitably those that are slow, or that spend much time at the surface, or that utilize habitats in the vicinity of major shipping lanes. However, records indicate that nearly all large whale species are vulnerable to ship strikes, particularly as vessel traffic increases in their waters.

Vessel speed has been implicated as a key factor in the occurrence and severity of vessel strikes with large species. Several independent studies indicate that vessel speeds of 10-14 knots increase by one-half or greater the probability that a whale will survive a collision with a ship.

As vessel traffic increases in the Barents Sea, modifications to customary vessel operation in key cetacean aggregation areas or vessel speed restrictions may be an effective measure to mitigate potential impacts on vulnerable species such as bowhead whales and, to a lesser extent, narwhals, beluga whales and other Arctic marine organisms. Where feasible, vessel routing measures may also be applied in order for ships to avoid known cetacean aggregation areas. A number of steps have been taken by some states outside the Arctic region to reduce the threat of ship strikes to endangered large whale species, including shifting shipping lanes and applying to the IMO to establish a vessel "Area to be Avoided." The issued the International Maritime Organization, which is in charge of regulating shipping around the world, issued in 2009 a non-mandatory guidance document aimed at the global maritime industry to minimize the risk of collisions between ships and whales aimed at the global maritime industry (Arctic Council, 2009).

4.4.4.3 Introduced species (ballast water)

Introduction of non-indigenous species introduced through ballast water or on hulls can have large impacts on ecosystems. No such impacts have been observed in the Barents Sea.

4.4.4.4 Expected development (during the next 5 years)

Future shipping activities depend considerably on the expansion rate of the oil-and-gas related industry in the northern areas, which in turn depends on both regional and global economic developments. Global warming and a subsequent increase of ice-free shipping routes through Arctic waters could also significantly contribute to increase of shipping traffic.

Arctic development issues are in focus in Russia. Some years ago, major Russian oil companies had ambitious plan to build a 100 million ton trunk oil pipeline from the Western Siberia to Murmansk. The project did not go through, but new initiatives on development of Russian railways, Arctic ports and NSR came into the agenda. During the next 5 years, the northern Timano-Pechora oil fields and Varandey terminal will transport about 10 million tonnes of crude a year and play a major role in oil shipments increase from the Russian Barents. The Prirazlomnaya platform in the Pechora Sea, that started production in 2013, should produce about 6 million tonnes of oil when it becomes fully operational which will be exported by ship. Yamal LNG and Novy Port terminal that are under construction in the Ob Bay will export most of produced LNG, gas condensate and crude oil westwards via the Barents Sea. When the plan for development of Murmansk Transportation Complex is realised, we will see more oil and refined products coming north by the railway. Table 4.4.8 gives an overview of existed and prospected capacities of the main terminals shipping Russian crude oil and petroleum products for export.

The liquid natural gas (LNG) plant at Melkøya is shipping LNG, liquefied petroleum gas (LPG), and gas condensates. Working at full capacity, Melkøya ships about 5 million tonnes of LNG, LPG, and gas condensate per year. This results in about 70 annual shipments of gas from Melkøya, in addition to about 300 tankers carrying Russian export petroleum cargoes westwards along the Barents Sea coast.

Table 4.4.8. Existing and prospected capacities of main Arctic terminals off-loading Russian crude oil and petroleum products for export (in thousands tonnes) (Bambulyak and Frantzen, 2011; Bambulyak et al., 2015b).

	Capacity		
Terminal locations	**2002**	**2013**	**2018**
Sabetta, Kara Sea	500’		*15 000’*
Novy Port, Kara Sea	-	600’	*8 500’*
Varandey, Pechora Sea	1 500’	12 500’	*12 500’*
Prirazlomnoye, Pechora Sea	-	-	*6 500’*
Arkhangelsk, White Sea	2 500’	4 500’	*7 000’*
Vitino, White Sea	4 000’	11 000’	*12 000’*
Murmansk, Barents Sea	2 000’	8 000’	*8 000’*
Mokhnatkina Pakhta, Barents Sea	-	2 500’	*2 500’*
Lavna, Barents Sea	-	-	*25 000’*

An increasing share of container ships and bulk cargo can be expected if the published plans for development of terminals in Murmansk, Kirkenes, and/or Narvik are realised (Rautio and Bambulyak, 2012).

Following 2014, several gas and oil fields may come into operation during the next five years. From the west, Goliat was planned to go into operation in late 2015. In the Kara Sea, huge gas fields on Yamal (Tambey fields) may ship LNG and condensate from Sabetta port and Yamal.

Shipments of LNG and gas condensate from the Shtokman field in the Russian sector of the Barents Sea had been expected to start in 2014, but the project has been postponed to indefinite time.

No significant changes are expected in the volume of ship traffic due to fishery activities in the area. There are considerable seasonal variations in the fishing industry. This applies especially to the maritime fishing fleet with its large cruising range.

The forecasts for future volumes of dangerous goods shipments are not clear. Assuming that Europe remains the primary market for Russian oil, there are estimates that forecast a steady increase from 15 million tonnes in 2010 to 50 million tonnes in 2025. Other forecasts can be built assuming that Asia or North America will become major markets for Russian arctic oil and gas.

Container ships are a rather new phenomenon in this region. These vessels are becoming increasingly larger, and they carry large amounts of bunker fuel. Container ships are more vulnerable to bad weather and high seas, especially with regard to shifting cargo. An increase in traffic for this type of vessel may thus imply a higher risk of acute pollution events unless considerable measures are put in place to mitigate this.

Shipping traffic will increase in correlation with petroleum activities in the region. If the extent of petroleum activity increases considerably, the volume of petroleum-related ship traffic will also increase. As a consequence, the risk of acute pollution from this traffic will also increase, unless an efficient emergency pollution prevention system is established.

The Ballast Water Management Convention (2004) regulates discharges of ballast water and sediments. Implementation and the general increase in awareness of the problems associated with ballast water are expected to reduce the risk of negative impacts on the environment. It is much more difficult to reduce the risk of introduction of non-indigenous species attached to ships' hulls. This is because the most effective anti-fouling systems themselves have negative impacts on the environment. IMO have recently started discussing regulation of organisms attached to ships hulls.

Risk of accidental discharges

See also Chapter 4.4.2.

In the Norwegian management plan for the Norwegian part of the Barents Seas (Report no 8 to the Storting), there is given a qualitative comparison of risk levels by analyses of the current situation (2005) and activity scenarios for 2020. The maritime transport currently involves a higher level of risk exposure in the management plan area than the expected risk exposure from all planned activities in 2020. However, this conclusion was based on assumptions relating to knowledge development, technological advances, and the introduction of traffic separation schemes between 2005 and 2020, in line with existing plans in 2005, and may be affected by new or future activities. Despite the expected increase in the volume of maritime transport by 2020, the analyses indicated that the implementation of measures such as a minimum sailing distance from the coast, traffic separation schemes and vessel traffic service centres would reduce the risk of oil spills associated with maritime transport by half from 2003 to 2020, and that the environmental consequences in 2020 should be comparable with those in 2003.

4.4.5 Aquaculture

Aquaculture is a growing industry along the coasts of northern Norway and Russia; there are several commercial fish farms producing salmonids (salmon, and trout), white fish (mainly cod), and shellfish. Aquaculture is dominated by salmon and trout. Norwegian farmed Atlantic salmon accounts for over half of the world's salmon supply. While landed catch has in general shown a declining trend, aquaculture production has increased steadily (FAO, 2013).

Russia's salmon aquaculture sector is also growing rapidly, and the outlook is good for Russian Atlantic salmon production particularly in the Murmansk region. Since early 2013, Russia has experienced a rise in production from its aquaculture sector. In 2011, the company's production of farmed salmon was 8,500 tonnes and by the end of this year, this amount is expected to increase to 21,000 tonnes. A second salmon farm was planned to be launched in the Barents Sea during 2013 in Ura Bay, where around 1.6 million Atlantic salmon smolts expected to be placed into farming operations and first salmon harvest planned for 2014. Two additional sites were planned for initiation in 2014.

The future of aquaculture in the Barents Sea can be viewed from the perspective of how a warming climate may impact the aquaculture industry. Higher water temperature is generally expected to have positive effects on aquaculture in terms of fish growth. The IPCC reported that warming and consequent lengthening of the growing season could have beneficial effects with respect to growth rates and feed conversion efficiency. The Intergovernmental Panel on Climate Change (IPCC) reported that warming and consequent lengthening of the growing season could have beneficial effects with respect to growth rates and feed conversion efficiency (IPCC, 2001). The aquaculture industry is dependent on capture of wild fish for salmon feed. Climate change may cause a lack of and/or variability in the market for such products, but this is also an area where research may lead to the development of other feed sources.

However, expansion of the aquaculture industry gives rise to a number of concerns, including: the intrusion of fish farms into vulnerable marine and coastal areas; 2) the impacts of aquaculture on the marine environment; and the overall sustainability of an industry that depends on large catches of wild fish to feed farmed fish (Nagoda, 2014).

4.4.5.1 Escapement/Genetic mixing with wild fish

An increase in severe weather events can be a cause of escapes from fish pens and consequent loss of production. Escapement is also a potential problem in terms of the spread of disease.
However, technological developments may compensate for this (ACIA, 2013). Breeding of escaped farmed fish also potentially results in genetic changes which may reduce the

population fitness and productivity in wild populations (McGinnity et al., 1997; Hindar et al., 2006).

4.4.5.2 Spreading sea (salmon) lice to wild fish

Warmer waters may also have negative effects on aquaculture since the presence of lice and diseases may be related to water temperature. In recent years high water temperatures in late summer have caused high mortality at farms rearing halibut and cod, the production of which is still at a pre-commercial stage. Salmon is also affected by high temperatures and farms may expect higher mortalities of salmon. A rise in sea temperatures may therefore favor a northward movement of production, to sites where the peak water temperatures are unlikely to be above levels at which fish become negatively affected (ACIA, 2013).

4.4.5.3 Water fouling

Poorly managed and poorly regulated aquaculture operations can have severe negative impacts on marine environments through the release of excessive nutrients and chemicals. Escapement of farmed fish increases the risk of disease transfer. The extraction of freshwater from rivers may also have a severe impact on the river habitat. Discharge of waste water can contain harmful concentrations of nutrients, chemicals and be a potential source for infection of, for example, the lethal salmon parasite *Gyrodactylus salaris* (Nagoda, 2014).

4.4.5.4 Feeding farm-raised fish

The aquaculture industry is dependent on capture fish for salmon feed. Accordingly, another important aspect of the aquaculture industry is its dependence on a huge supply of pelagic fish species as capture fish for salmon feed. Fishmeal and oils are important components of the diet of many species of farmed fish, including salmon and trout. The quantity needed is so high that the industry at a global level is sensitive to rapid fluctuations in important pelagic stocks. Reduced supply pelagic species on the international market could lead to increased prices of fishmeal. Climate change may cause a lack of and/or variability in the market for such products, but this is also an area where research may lead to the development of other feed sources (ACIA, 2005). A recent assessment by the IPCC states that unless alternative sources of protein are found, aquaculture could in the future be limited by the supply of fishmeal and oils (Vilhjálmsson et al., 2013).

4.4.6 Tourism

The Barents Sea ecosystem is driven by climate conditions and is highly susceptible to the effects of climate change; it is inherently a highly dynamic system. Human forces now present in the system and are already affecting environmental conditions. Within this unstable setting, a rapidly growing tourist industry is also producing change and exerting impacts. It is important to anticipate ways in which tourism will affect the environmental quality, cultural integrity, economic structure, and governance within the Barents Sea region. It is also likely that tourism itself will be impacted by the natural and human-induced changes now occurring and anticipated to occur. Evaluating the extent of those vulnerabilities and then applying appropriate responses to prevent negative impacts on the Barents Sea ecosystem is the challenge to sustainable development. An appropriate response to that challenge may require selection of sustainable development objectives, and identification of management techniques which incorporate best practices to accomplish those objectives. The United Nations Environment Programme (UNEP) and the World Tourism Organization (UNWTO) have formulated principles for the advancement of sustainable tourism (UNEP/UNWTO, 2005) which emphasize:

• Conserving environmental quality;
• Preserving cultural and social values by means of participatory decision-making;
• Creating sustainable economies; and
• Ensuring positive visitor behavior, safety, and enjoyment.

4.4.6.1 Tourism in Norway

Tourism is one of three focus areas for business in Svalbard, and has been so since the last White Paper Number 50 (1990-91) Næringstiltak på Svalbard (Measures for Economic development of Svalbard) was presented. Cruise tourism is a major part with high numbers of operators, vessels, and ships; the cruise tourism industry in Svalbard has increased considerably over the last 10-15 years transporting a large number of passengers. There are two types of vessels: overseas cruise ships; and expedition cruise ships. In addition, day cruise ships operate in Isfjorden. Cruises started as early as in 1891; industry statistics have been reported since 1996. By establishing the Association of Arctic Expedition Tour Operators (AECO) in 2003, the industry took a major step forward establishing guidelines for member activities to meet regulatory challenges.

The number of sites where passengers come ashore rose steadily from 1996 to 2000. More small expedition cruise vessels appeared and began to visit new areas at new landing sites, including eastern Svalbard. The number of tourist passengers going ashore, however, remained reasonably stable. From 2001 onwards, all operators have reported their activities. The number of tourists going ashore increased approximately 45 % during 2001-2008, and peaked in 2009; the numbers dropped during 2010-2011, most likely due to decreased private economies. The numbers of passengers increased to approximately 9,000 during 2011-2012 to a similar level as in 2005; this increase continued through 2013. Overseas cruise ships have been responsible for most of increased marine tourism since 2001; although expedition cruise vessels have also contributed significantly.

The number of landing sites increased steadily from 120 in 2001 to a peak of 165 in 2005, and stabilized at 145-150 sites during the period 2006-2009. Since then, the number has continued to increase; a total of 189 landing sites were active in 2013. This is due, in part, to a new type of product «Sail & Ski» where off-piste skiing — skiing fresh, unadulterated powder — is the main activity. Overseas cruise ships normally have passengers go ashore at one or two places in Svalbard (Magdalenefjorden and sometimes Møllerhamna), apart from the settlements. The ban on use of heavy crude oil, limits on the number of passengers, and restricted access to cultural heritage sites have altered the sailing routes of large ships and protected vulnerable areas in eastern Svalbard.

The number of overseas cruise ships visiting Svalbard has varied between 21 and 34, but increased in 2012 (Figure 4.4.27). The number of expedition cruise vessels has fluctuated between 15 and 35, with an increased number of smaller vessels. In 2013, there were fewer ships sailing, but an increased number of passengers. Until 2007, the authorities placed no particular limitations on development of this industry, but landing restrictions and increasing self-applied control through AECO will affect the future development. Declines seen after the 2008-2009 financial downturn in Europe have since been reversed, and there is now a degree of optimism. The introduction in 2015 of a general ban on use of heavy crude oil is cause for concern regarding visits from overseas cruise ships. It should be noted that several expedition cruise vessels join in the annual Clean-up Svalbard activities by helping to remove marine debris that has drifted ashore http://www.aeco.no/2014/07/clean-up-svalbard/.

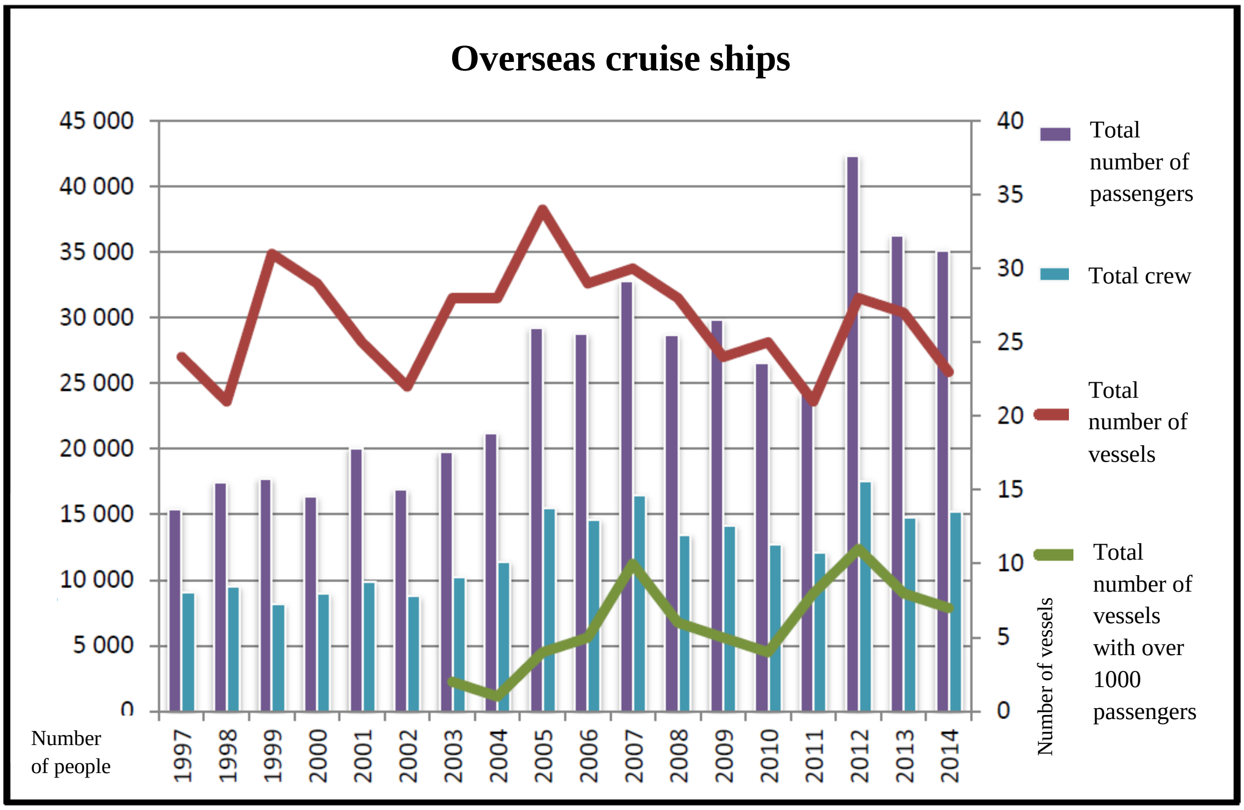


Figure 4.4.27. Summary of overseas cruise ship activity in Svalbard, Norway during 1977-2014.

4.4.6.2 Arctic tourism in Russia

In December 2013, the Murmansk regional government decreed that the role of tourism in economic and socio-cultural development of the region should be increased. Cruise tourism is recognized as a key area for further development. To develop the infrastructure to ensure regular marine passenger transport, the "Arctic Harbor" investment project will be implemented. Within the project's framework, a range of improvements are planned, including: reconstruction of buildings, and piers for long-distance lines at port areas and marine terminals; and the first nuclear-powered icebreaker "Lenin" being permanently stationed at the harbor. Marine terminals will also accept passenger cruise ships, presenting an opportunity to open a regular ferry line Kirkenes - Murmansk.

During 2014, there were five cruises to the North Pole, including entrance into the Federal Reserve territory “Zemlya Frantza Iosifa” with the nuclear icebreaker “50 Let Pobedy” (Figure 4.4.28). In addition, the diesel icebreaker “Kapitan Dranitzytn” is used to visit the Franz Josef Land archipelago.

Figure 4.4.28. Route of the nuclear icebreaker “50 let Pobedy” carrying tourists to the North Pole.

During the 2014 season, 738 tourists from over 30 countries visited the National Park “Russkaya Arktika” and Federal Reserve “Zemlya Frantza Iosifa”. Almost 40% of the visitors were from the Peoples Republic of China. The reserve has plans to open the border control point on Franz Josef Land in 2015 to process admission of foreign visitors. In addition, the administration of National Park “Russkaya Arktika” hopes for a decree to expand the territory of the National Park “Russkaya Arktika” by including the Federal Reserve “Zemlya Frantza Iosifa” into its territory.

The Joint Stock Company (JSC) «LUKOIL Oil Company» “Atomflot” organized four cruises from Murmansk aboard the nuclear icebreaker “50 Let Pobedy” during on the following dates in 2015 (http://www.sodis-camp.ru/). However, it has been reported that as of 2016, there will be no more tourist cruises to the North Pole and Franz Josef Land with the nuclear icebreakers due to further utilization of the icebreakers exclusively for their intended purpose. Apparently, there will still be cruises with the diesel icebreaker “Kapitan Dranitzyn”, but only to the Franz Josef Land and Novaya Zemlya.

In addition, various natural attractions of the Murmansk region and Nenets Autonomous District allow the development of environmental tourism. There are three protected areas on the Kola Peninsula: Kandalaksha Reserve (70.5 thousand hectares), “Pasvik” reserve (14,727 thousand hectares), Lapland reserve (268,4 thousand hectares), as well as Kolguev and Vaigach islands, bird cliffs and marine mammal haul-outs in the Pechora sea on Russkiy Zavorot peninsula and Lovetzkiy, Dolgiy-1, Dolgiy-2, Zelenetz and Matveev islands.

4.4.7 Bioprospecting

Having access to diverse marine habitats in the western part of the Barents Sea, a maritime and marine heritage, and existing strengths in marine biotechnology, the Norwegian government supports marine bioprospecting as a source of new and viable wealth creation. Accordingly, in 2002 the Norwegian Government established a National Plan for Functional Genomics (FUGE Programme), which aims to establish ‘the research basis needed to promote further development of the aquaculture industry, optimal utilization of marine resources, and the creation of a biomarine industrial cluster in Norway’. A national strategy has been developed towards this end, and investments are being made to develop a national infrastructure for research and development (FKD, 2009). Scientists from several nations are conducting research characterized as bio-prospecting. Biotechnology based on Arctic genetic resources covers several key areas, including: enzymes (including those used in life science research and a range of industrial applications); anti-freeze proteins; bioremediation; pharmaceuticals; nutraceuticals and dietary supplements; cosmetics; and other health care applications. There is also a significant focus of marine biotechnology research and development (R &D) (Leary, 2008).

4.5 References

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5 Future prospects

K. Drinkwater (IMR), A. Filin (PINRO), P. Arneberg (NPI), S. Belikov (VNIIPriroda), *M. Gavrilo (AARI), L.L. Jørgensen (IMR), K.M. Kovacs (NPI), P. Luybin (PINRO), M.M. McBride (IMR), M. Reigstad (UiTø), and H. Strøm (NPI)*

5.1 Effects of climate change on the ecosystem and human activities

Over the last 50 years, air temperatures have increased almost twice as fast in the Arctic than the global average. Models predict that air temperatures will continue to increase considerably, and summer sea ice in the Arctic is likely to disappear before the middle of this century and winter sea ice by the end of the current century (IPCC, 2013). Because of the complex dynamics of the Barents Sea ecosystem, and because the effects of climate change will interact with other major factors, such as acidification and the impact of fisheries, it is difficult to predict what the total effect on this ecosystem will be. However, it can be predicted with fair certainty that some of the ice-associated fauna and flora in the Barents Sea will be lost or at least significantly reduced. Also, a number of species, e.g. cod and capelin, will likely have a more northern and/or eastern distribution and boreal species such as blue whiting and mackerel may become common in the Barents Sea. These changes will likely result in potentially large changes in community composition, and it is possible that the structure of the ecosystem may shift irreversibly. The probability of this happening may increase if the pressures from other types of impacts, such as fisheries and acidification, are high.

5.1.1 Projections of future climate change – Global perspective

On the global level, the Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. IPCC's most recent and Fifth Assessment Report (AR5) was released between September 2013 and November 2014. The main conclusion of AR5 is that "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen".

One of the main reasons for global warming is cumulative emissions of CO_2 (IPCC, 2013). Projections of future anthropogenic greenhouse gas (GHG) emissions vary over a wide range depending on both socio-economic development (mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, and technology) as well as climate policy. AR5 used Representative Concentration Pathways (RCPs) for developing various future scenarios of GHG levels. They described four different 21st Century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') led to pathways ranging between RCP6.0 and RCP8.5 (Figure 5.1.1). RCP2.6 is representative of a scenario that aims to keep global warming likely below 2°C above pre-industrial temperatures.

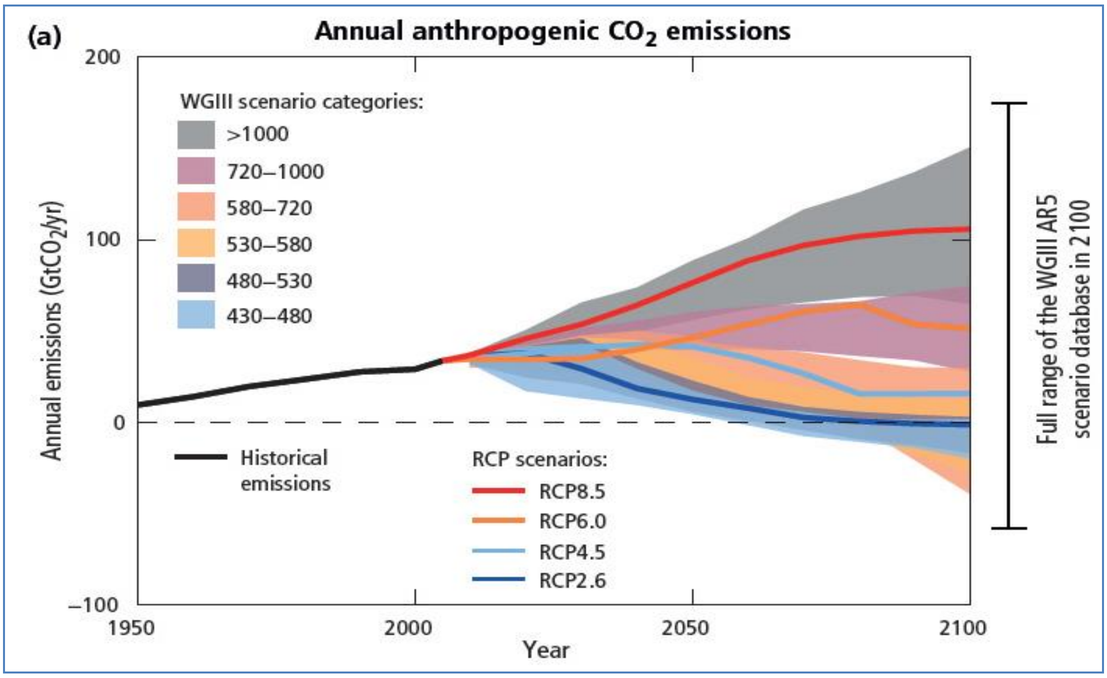

Figure 5.1.1. Annual emissions of CO_2 in gt yr^{-1} showing the mean and the range for different RCPs.

Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO_2 emissions and projected global temperature change to the year 2100 in both the RCPs and the wider set of mitigation scenarios. Based upon the CO_2 emission variants the AR5 concluded: "surface temperature is projected to rise over the 21st Century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise".

The global mean surface air temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will likely be in the range 0.3°C to 0.7°C (medium confidence) (Figure 5.1.2). The assumptions in developing the simulations were that there will be no major volcanic eruptions or changes in some natural sources (e.g., CH_4 and N_2O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario.

The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is likely to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.59. The AR5 conclude "the Arctic region will continue to warm more rapidly than the global mean".

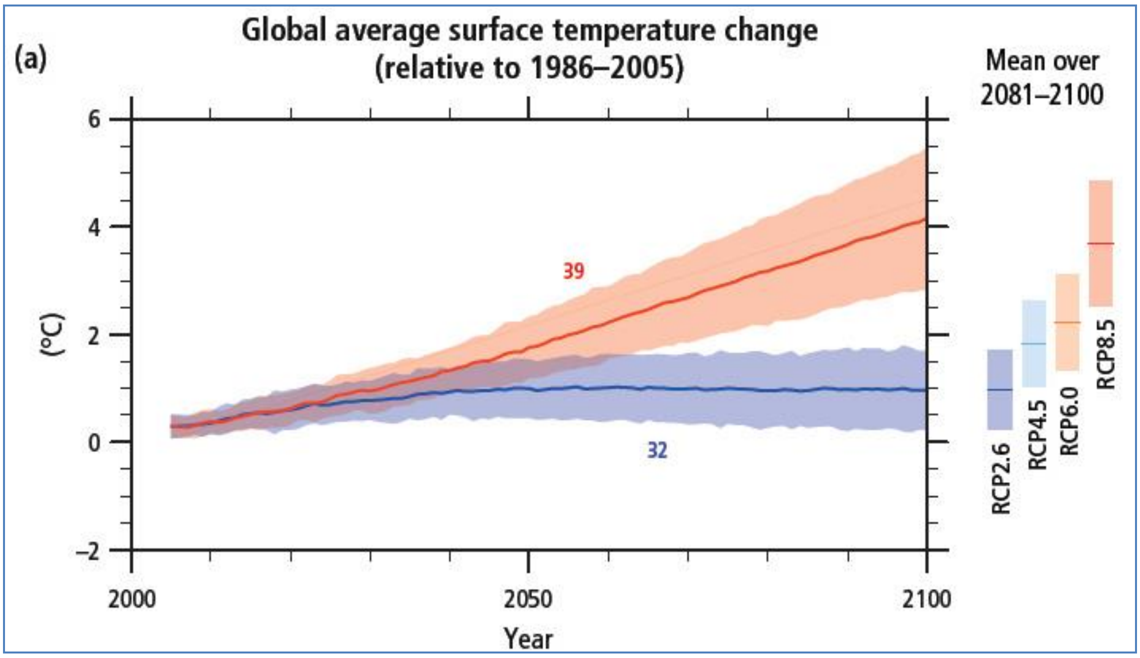

Figure 5.1.2. Global average surface temperature change **(a)** from 2006 to 2100 as determined by multi-model simulations. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as colored vertical bars at the right hand side of panel. The number of Coupled Model Intercomparison Project Phase 5 (CMIP5) models used to calculate the multi-model mean is indicated.

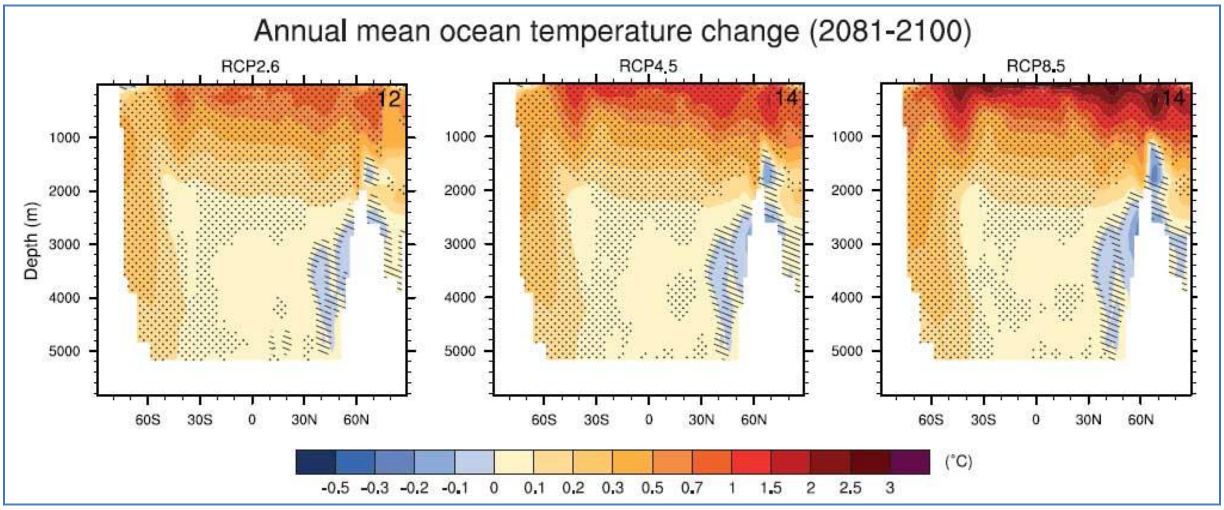

Figure 5.1.3. Annual mean zonal temperature change in the ocean for 2081-21000 relative to 1986–2005 under RCP2.6 (left), RCP4.5 (centre) and RCP8.5 (right) forcing scenarios. Hatching indicates regions where the multi-model mean change is less than one standard deviation of the internal variability. Stippling indicates regions where the multi-model change mean is greater than two standard deviations of the internal variability and where at least 90% of the models agree on the sign of change

Figure 5.1.3 shows the multi-model mean projections of zonal-averaged ocean temperature change under three emission scenarios. Differences in projected ocean temperature changes for different RCPs become more distinct as the century progresses. The largest warming is found in the top few hundred meters of the subtropical gyres, similar to the observed pattern of ocean temperature changes (Levitus et al., 2012). Surface warming varies considerably between the emission scenarios ranging from about 1°C (RCP2.6) to more than 3°C in

RCP8.5. Mixing and advection processes gradually transfer the additional heat to deeper levels of about 2000 m at the end of the 21st century. Depending on the emission scenario, global ocean warming between 0.5°C (RCP2.6) and 1.5°C (RCP8.5) will reach a depth of about 1 km by the end of the century. This figure also shows that on latitudes higher than 75°N for all scenarios the water temperature will increase.

In the Technical summary of WG1 for AR5 it was noted that the Arctic sea-ice cover, very likely, will continue shrinking and thinning year-round during the course of the 21st century (Figure 5.1.4).

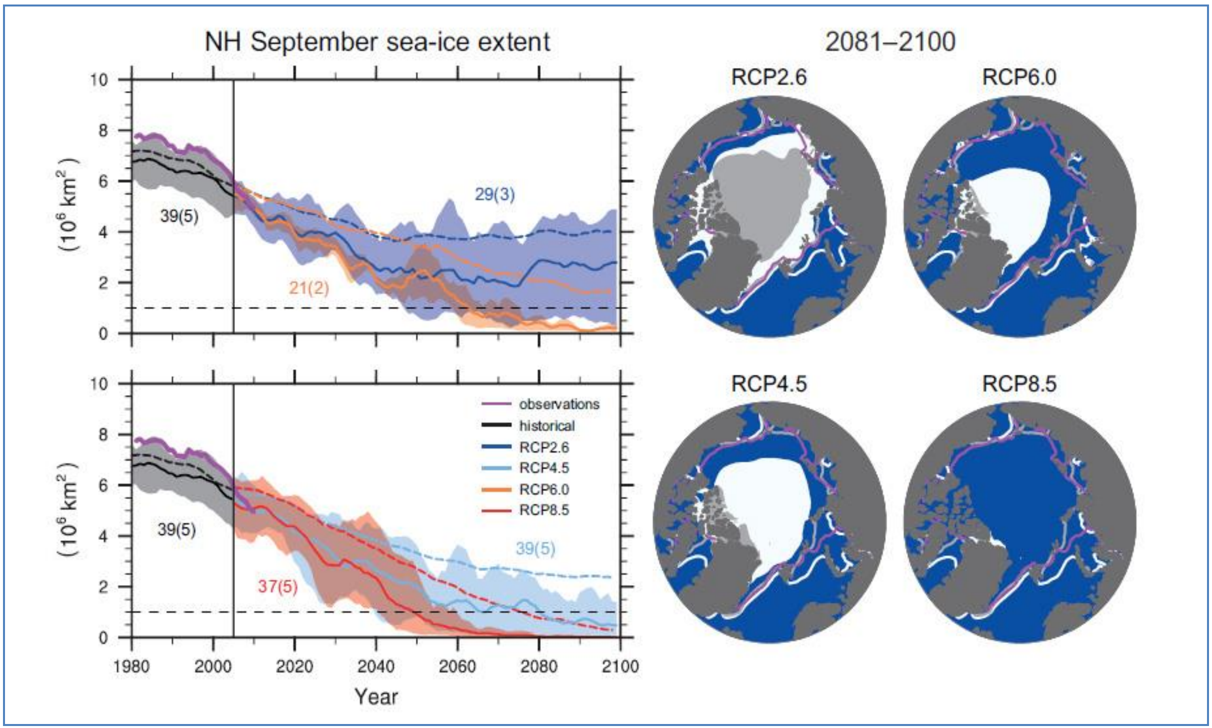

Figure 5.1.4. Northern Hemisphere (NH) sea-ice extent in September over the late 20th century and the whole 21st century for the scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in the CMIP5 models, and corresponding maps of multi-model results in 2081–2100 of NH September sea-ice extent. In the time series, the number of CMIP5 models to calculate the multi-model mean is indicated (subset in brackets). Time series are given as 5-year running means. The projected mean sea-ice extent of a subset of models that most closely reproduces the climatologic mean state. The 1979–2012 trend of the Arctic sea ice is given (solid lines), with the minimum to maximum range of the subset indicated with shading. Black (grey shading) is the modeled historical evolution using historical reconstructed forcing. The CMIP5 multi-model mean is indicated with dashed lines. In the maps, the CMIP5 multi-model mean is given in white and the results for the subset in grey. Filled areas mark the averages over the 2081–2100 period, lines mark the sea ice extent averaged over the 1986–2005 period. The observed sea-ice extent is given in pink as a time series and averaged over 1986–2005 as a pink line in the map.

The CMIP5 multi-model projections give average reductions in Arctic sea-ice extent for 2081–2100 compared to 1986–2005 ranging from 8% for RCP2.6 to 34% for RCP8.5 in February and from 43% for RCP2.6 to 94% for RCP8.5 in September (medium confidence). A nearly ice-free Arctic Ocean (sea-ice extent less than 106 km2 for at least five consecutive years) in September before mid-century is likely under RCP8.5 (medium confidence), based on an assessment of a subset of models that most closely reproduce the climatological mean state and 1979–2012 trend of the Arctic sea-ice cover. Some climate projections exhibit 5- to 10-year periods of sharp summer Arctic sea-ice decline - even steeper than observed over the last decade - and it is likely that such instances of rapid ice loss will occur in the future. There is little evidence in global climate models of a tipping point (or critical threshold) in the transition from a perennially ice-covered to a seasonally ice-free Arctic Ocean beyond which further sea ice loss is unstoppable and irreversible.

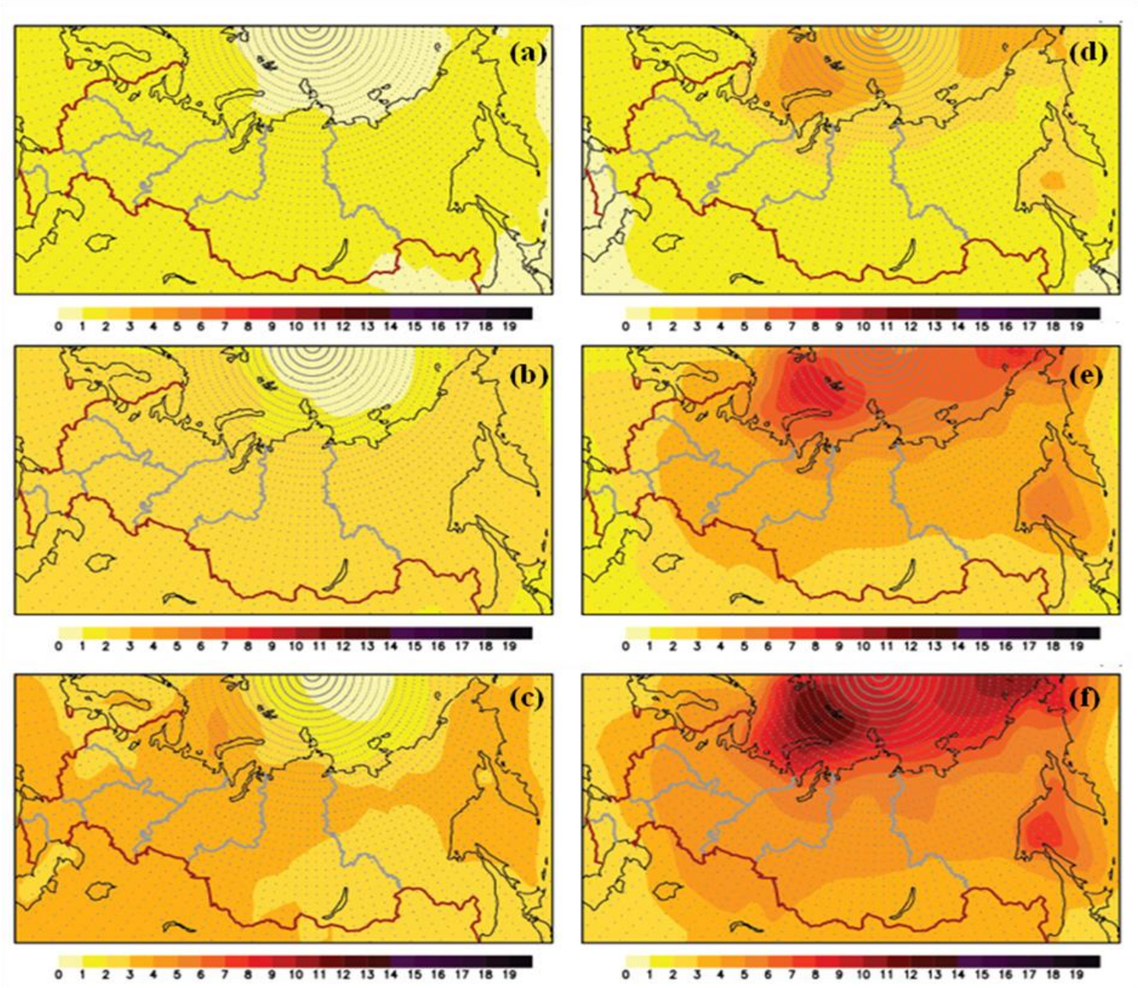

Figure 5.1.5. The mean anomalies of the surface air temperature for 2011–2030 (a, d), 2041–2060 (b, e) and 2080–2099 (c, f) by the end of the 21st Century for summer (a, b, and c) and winter (e, f, and g). The simulations were based on an ensemble of 31 CMIP5 models using RCP4.5 scenarios.

5.1.2 Projections of future climate change – Barents Sea

Projections for future changing surface air temperature over Russia and marine areas including the Barents Sea (Figure 5.1.5) and precipitation (Figure 5.1.6) for 2011-2030, 2041-2060 and 2080-2099 appeared in the Second Assessment Report for Climate Change in Russia. In the Barents Sea, surface air temperature will increase more in winter (Figure 5.1.5 d, e, and f) than in summer (a, b, c). For winter, the maximum anomalies are situated between Svalbard and northern Novaya Zemlya for all periods and gradually increase from 2011-2030 (6-7^{0}C) to 2080-2099 (11-12^{0}C). In summer, the maximum anomaly area for 2080-2099 is situated in the central part of the sea and near the southern part of Novaya Zemlya; and the anomalies gradually increase from 2011-2030 (1-2^{0}C) to 2080-2099 (4-5^{0}C).

Precipitation is also projected to increase, being higher in winter (Figure 5.1.6 d, e, and f) than in summer (a, b, and c). For winter, the maximum precipitation anomalies are situated between Svalbard and the southern coast of Russia for all periods and gradually increase from 2011-2030 (20-25%) to 2080-2099 (40-45%). For summer, the maximum anomalies are situated in the northern Barents Sea and the anomalies gradually increase from 2011-2030 (5-10%) to 2080-2099 (15-20%).

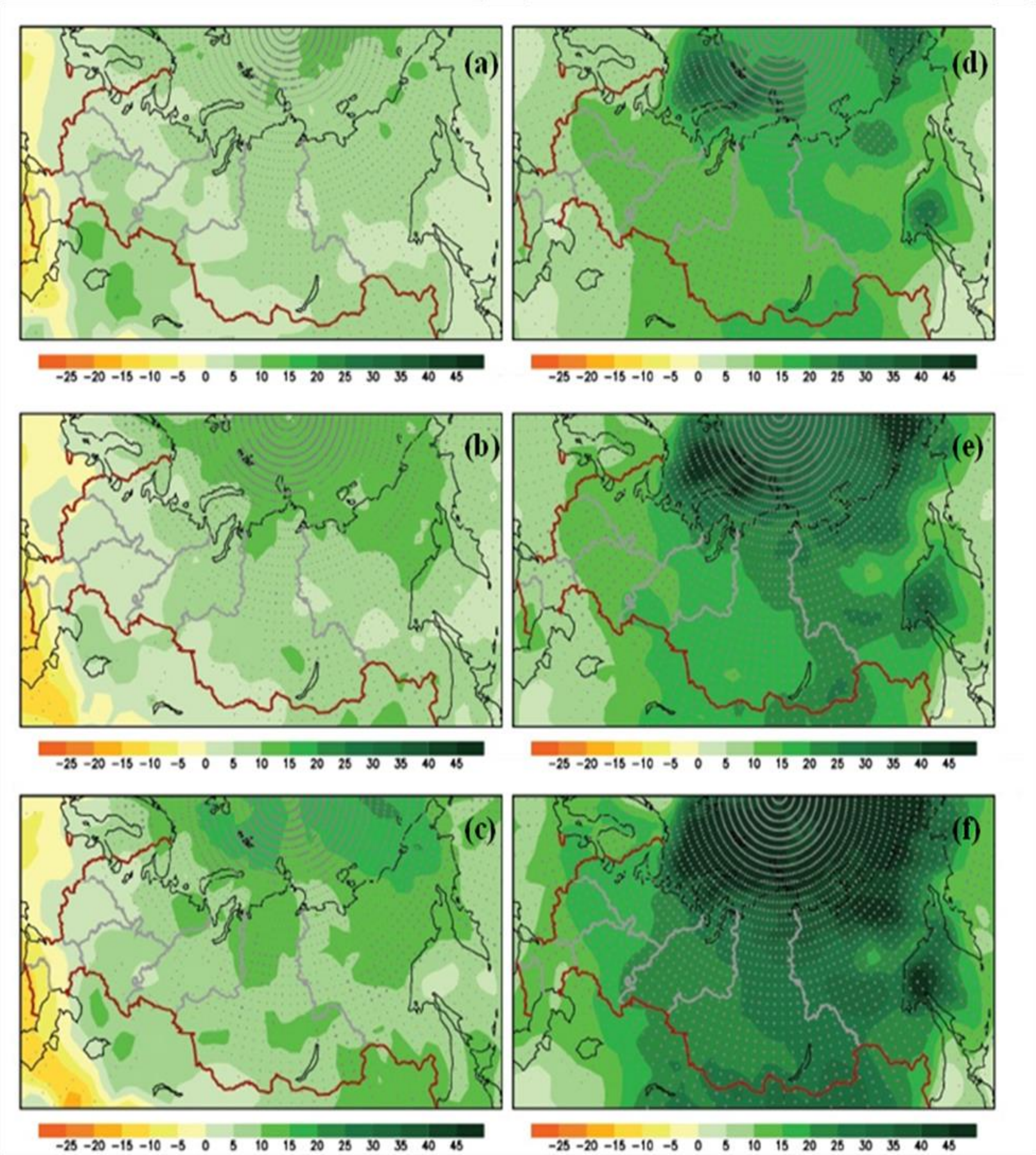

Figure 5.1.6. The mean precipitation anomaly (%) for 2011–2030 (a, d), 2041–2060 (b, e) and 2080–2099 (c, f) for summer (a, b, c) and winter (d, e, f) based on an ensemble of 31 CMIP5 models using RCP4.5 scenarios.

5.1.3 Projections of future physical oceanographic conditions - Barents Sea

A number of early projections of oceanographic conditions for the Barents Sea have been made. Furevik et al. (2002) suggested that by 2080, surface ocean temperatures would warm by 1° to 2°C, winter sea ice would almost disappear, Atlantic Water would spread farther eastward and northward, and the surface mixed-layer depth would increase due to stronger winds. Ellingsen et al. (2008) suggested that sea-ice coverage will decrease with the largest decline in summer and virtually ice-free summer conditions by 2059. A 25% increase in freshwater runoff to the Barents Sea and a peak spring discharge 2-3 weeks earlier than at present was projected by Dankers and Middelkoop (2008). In spite of this, an increase in future salinity has been predicted owing to higher salinities in the Atlantic Water inflows caused by higher evaporation in the tropics (Bethke et al., 2006).

Huse and Ellingsen (2008) examined changes in position of the Polar Front that separates the cold Arctic and warm Atlantic Water. The frontal position was projected not to change much in the western Barents, where it is tied to topographic features, but in the eastern Barents the front was projected to move farther north and east. In a more recent study by Wassmann et al. (2015), using a Regional Circulation Model (RCM) called SINMOD, it is suggested that the front may move all the way to the northern shelf break adjacent to the Arctic Ocean (Figure 5.1.7). This would result in much warmer waters, especially in the northern Barents Sea (Figure 5.1.7 A, C).

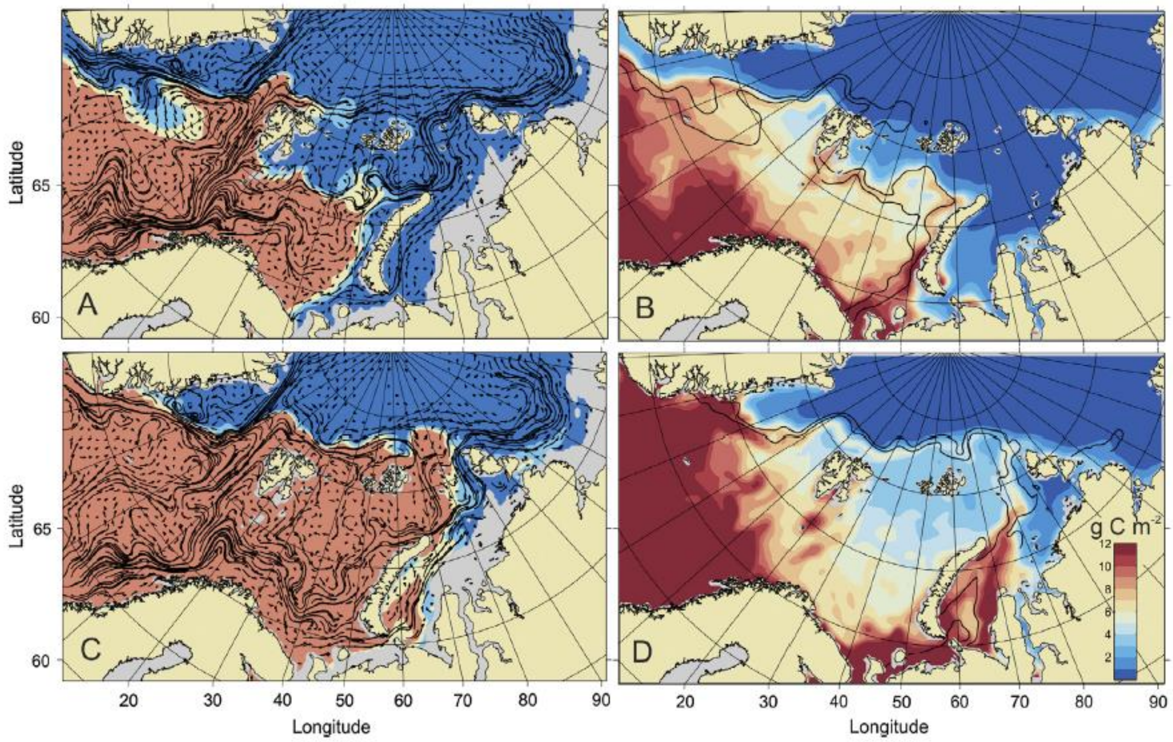

Figure 5.1.7. The average position of the Polar Front in April. The frontal position is indicated by the boundary between the waters less than -1°C (blue) and above +1°C (red) in panels A and C. Also shown in these panels is the average current vector at 50 m depth. The gross primary production for April is shown in panels B and D. The years 2000-2009 are displayed in A and B while 2090-2099 are in C and D.

Most of the future climate scenarios that have been developed for the Barents Sea are based on low resolution (order 100 kms) Global Circulation Models (GCMs). More recently, Regional Climate Models (RCMs) have been developed with much higher spatial resolution (order 10s of kms). Sandø et al. (2014) used two GCMs, the GISS Ocean-Atmosphere Model and the NCAR CCSM3, to downscale to a regional model of the Barents Sea based on the Regional Ocean Modelling System (ROMS). The two global models were chosen based on their performance to recreate sea ice conditions in the Barents Sea (Overland and Wang, 2007). The downscaling results for present day conditions in the Barents Sea were closer to the observations than for the two GCMs and the differences between the downscaled results from the two models was less than the differences between the two GCMs. However, the future scenarios from the two downscaled models were significantly different. The downscaling using the NCAR model resulted in much higher heat transport into the Barents Sea and water masses became less saline compare to using the GISS model. The authors concluded that the RCM results depend largely on the GCM chosen to downscale from and hence exactly what will happen in the Barents Sea under climate change remains somewhat uncertain. One approach to overcome the dependency on a particular GCM would be to undertake the downscaling using several GCMs and then take an ensemble mean. This should provide a better estimate while the spread in the models would indicate the uncertainty in the projections. Also, there is a need to couple the atmosphere and ocean for the regional models, which even in the recent modelling by Sandø et al. (2014) was not attempted. In a coupled model system, the changes in the ocean feedback to the atmosphere; in an uncoupled system, there is no feedback.

Under climate change, temperatures will rise in the Barents Sea somewhere between 2°-10°C; sea ice will be significantly reduced, and may disappear all together. Salinities are generally expected to decline due to increasing precipitation and higher river runoff. Peak river runoff will occur earlier in the year. The Polar Front will move in a northeast direction, and there will be greater amounts of Atlantic Water and less Arctic Water.

Recent studies have provided new insights regarding climate variability in the Barents Sea. Sandø et al. (2014) used results from the NorESM1-M coupled climate model to show that the negative trend in sea-ice coverage reflects the major trend of heat transport through the Barents Sea Opening. They concluded that the ocean has a stronger direct impact on changing sea-ice coverage than does the atmosphere. Smedsrud et al. (2013) similarly concluded that loss of ice cover in the Barents Sea is driven by increased transport of heat into the region with inflowing Atlantic Water. These authors also found that correlations between the Barents Sea ice coverage and the North Atlantic Oscillation are highly variable yet remain relatively low for extended periods of time. Drinkwater et al. (2014) supported earlier findings of a strong Atlantic Multidecadal Oscillation (AMO) like signal in Barents Sea temperature and in Arctic sea-ice variability. The AMO has a period of 60-80 years and is believed to be linked to changes in the Meridional Overturning Circulation.

5.1.4 Future foodwebs in the Barents Sea under climate change

Projected changes in the ocean climate indicated above will have significant impacts on the biology of the Barents Sea. A full discussion on the expected biological responses to the physical changes is beyond the scope of the present report. However, in the following we present some of the changes that may occur.

5.1.4.1 Plankton

In seasonally ice-covered areas where the ice will be reduced or disappear under climate change, annual primary production has been projected to increase because of higher light levels and an extended growing season (Arrigo et al., 2008). Indeed, satellite imagery has suggested a significant increase in net primary production within the Barents Sea between 1998 and 2006 (Mueter et al., 2009). Future projections vary slightly in terms of the estimated change in overall primary production in the Barents Sea. Ellingsen et al. (2008) suggested an increase of about 8% over a 65 year-long period, mostly occurring in the eastern and northeastern regions. No significant trend was found by Slagstad et al. (2011) as they examined the response to increases of 2° to 8°C in the waters of the Barents Sea. Skaret et al. (2014), on the other hand, projected an increase of 36% by 2046-2064 compared to 1981-1999, mostly in the northern and eastern regions. The varying results are owing to differences in model formulation and the greenhouse gas scenarios used. It is not only primary production that will be impacted. Ice algal communities will be lost or reduced as the sea ice declines. Also, earlier phytoplankton blooms are likely under a warming scenario through earlier onset of density stratification of the water column (Ji et al., 2013).

Earlier sea ice melt and the subsequent release of ice algal communities to the water column — at a time when surface waters are cold and zooplankton growth rates are low — could result in low zooplankton abundance and reduced grazing; thereby, increasing the sinking flux of particulate matter from the sea ice to the sediments (Arrigo et al., 2008). Leu et al. (2011) found evidence that a mismatch between the timing of ice break up and the growth period for *Calanus glacialis* caused up to a 5-fold decrease in their biomass. If advection of warm surface waters is primarily responsible for early losses of sea ice, zooplankton growth may not be negatively impacted and carbon export may remain unchanged or even diminish (Arrigo et al., 2008). Reduced sea-ice cover has been proposed to favour a pelagic-dominated ecosystem over the more typical sea-ice algae to benthos ecosystem (Piepenburg, 2005). Such an ecosystem switch would reduce the vertical export of organic carbon and decrease pelagic-benthic coupling, despite an overall increase in phytoplankton productivity.

Ellingsen et al. (2008) predicted that under climate change Atlantic zooplankton production, primarily *Calanus finmarchicus*, would increase by about 20% and spread farther eastward while the Arctic zooplankton biomass would decrease significantly (by 50%) resulting in an overall decrease in zooplankton production in the Barents Sea. The increase in Atlantic species biomass did not compensate for the losses of Arctic zooplankton resulting in an overall decrease of zooplankton biomass in the Barents Sea. The increased Atlantic zooplankton is caused by both increased transport into the Barents through inflow of warm

Atlantic water (Stenevik and Sundby, 2007) and to faster turnover rates due to the higher temperatures, as suggested by Tittensor et al. (2003) for the Labrador Sea. Indeed, the loss of Arctic species in the northern Barents Sea during recent years in association with warm temperatures and reduced ice cover has been observed (Dalpadado et al., 2012).

5.1.4.2 Fish and Shellfish

If warmer temperatures and sea ice reductions result in higher phytoplankton production in the Barents Sea, it is expected to result in increased fish production. For example, model studies suggest that higher primary production tends to increase cod recruitment in the Barents Sea (Svendsen et al., 2007). Drinkwater (2005) modelled the response of cod recruitment throughout the North Atlantic to future warming scenarios based upon previous responses to temperature variability. In the Barents Sea, he found increases in cod recruitment compared to present values under temperature increases of 1° to 4°C. Coupled with expected higher growth rates, there would be an increase in total cod biomass in the Barents Sea, which in turn could lead to increased fish catches (Drinkwater, 2005; Stenevik and Sundby, 2007). However, any increase in cod recruitment and abundance will depend on changes in secondary (zooplankton) production; particularly *C. Finmarchicus*, which is the primary prey for cod larvae. The expected increased abundance of *C. finmarchicus* in the Barents Sea under future climate change (Ellingsen et al., 2008), supports the contention that cod recruitment will likely increase. However, not all models agree. Kristiansen et al. (2014) predicted that cod production would decline later during the 21st century owing to a decrease in zooplankton productivity.

A northward and eastward shift in cod distribution under climate change was earlier suggested (Loeng et al., 2005; Drinkwater, 2005; Stenevik and Sundby, 2007; Cheung et al., 2008), with potential to penetrate as far as the Kara Sea (Drinkwater, 2005). Such shifts have already been observed with cod reaching a historic northward expansion in the Barents Sea at the continental shelf break adjacent to the Arctic Ocean (Kjesbu et al., 2014). In addition, more cod spawning is expected to take place in the north and less in the southern regions along the coast of Norway (Stenevik and Sundby, 2007; Sundby and Nakken, 2008). Distribution shifts for adults will result in a higher proportion of cod in Russian waters, although because of expected increases in total production, the number of fish in both the Norwegian and Russian economic zones is expected to increase. This should result in increased fish catches by both Norway and Russia under climate change (Loeng et al., 2005; Stenevik and Sundby, 2007).

Filin and Oganin (2008) reported on a quantitative analysis of the response of the cod stock in the Barents Sea to future climate changes using a fish-ecosystem coupled model that takes into account trophic interactions and environmental influences. Their model included cod as a predator and only capelin and juvenile cod as a prey. Simulation results indicated that raising the temperature in the Barents Sea by 1°-4°C will result in increased cod growth and earlier maturation. This will have a positive effect on general production of the cod stock, but cannibalism will also increase.

While these possible changes to Atlantic cod under future warming are consistent with past observations, the actual response remains uncertain. Indeed, Drinkwater (2005) noted that future cod projections will require both: improved understanding of the physiological and behavioural responses of cod to changes in environmental conditions; and improved understanding of the responses of other components of the marine ecosystem. Growth rates eventually will decrease at very warm temperatures, and cod movements result from complicated behavioural response(s) of individuals to multiple cues, and to gradients and variation in temperature as well as stock abundance. Competitors and predators will also influence the response of the cod to climate change. For example, if Atlantic mackerel (*Scomber scomberus*) expanded from the Norwegian Sea into the Barents Sea in substantial numbers it could significantly reduce the larvae and young juveniles of cod through predation. Clearly, the ultimate fate of cod will also depend upon the fisheries and hence fisheries management. The possible build-up of cod biomass in the Barents Sea will depend greatly on the level of fishing intensity (Drinkwater 2005, 2009). Eide (2008), examining the effect of different management regimes on Norwegian cod fisheries in conjunction with climate change, concluded that these management schemes will play a more significant role than climate change on the economic performance of the Barents Sea fishing industry.

Vikebø et al. (2007) examined the potential impact of a reduction in thermohaline circulation (THC) in the North Atlantic on the drift and hence growth and distribution of larval and juvenile North-east Arctic cod. The THC brings warm water north which cools, sinks and returns as a deep water current. Using the Regional Ocean Modelling System (ROMS), they imposed a 3 times greater than present river discharge into the Nordic Seas and the Arctic Ocean, which reduces the strength of the THC by 35%. This is near the projected reduction of around 25% in the THC predicted by the end of the 21st century in the IPCC (2007) report. Vikebø et al. (2007) found that this reduction results in fewer juvenile cod transported eastwards in the Barents Sea, and those that were transported were considerably smaller in body size because of cooler temperatures. More juvenile cod were transported to western parts of Spitsbergen, where feeding conditions are poorer and survival rate is lower than in the Barents Sea; this led to an overall increase in cod mortality for the year class. Some juveniles would possibly reach into the Arctic Ocean but were not expected to survive.

Although arguably cod is the most studied species in the Barents Sea in relation to the impacts of climate change, investigations of other species suggest that they also will be substantially impacted. Similar to cod, under the projected warming in the Barents Sea, other boreal fish species are expected to extend farther east and north (Drinkwater, 2005; Loeng et al., 2005; Stenevik and Sundby, 2007; Hop and Gjøsæter, 2013). The eastward extension of herring, blue whiting, and possibly Atlantic mackerel are expected to result in new species interactions and potentially changes in ecosystem structure and functioning. For example, substantial numbers of mackerel could reduce the cod population through predation on their larvae and young juveniles. Blue whiting has already increased significantly in the Barents Sea, but has not yet become a significant prey item for piscivorous fish (Dolgov et al., 2010). Capelin has been observed to have moved northward in response to the present warm temperatures and reduced ice (Ingvaldsen and Gjøsæter, 2013). Cheung et al. (2009) suggested that the Barents

Sea would be expected to see a relatively large number of invasive species, local extinctions, and hence species turnover related to distributional shifts. One population that was estimated to disappear from the Barents Sea — within approximately 30 years of warming temperatures and reduction in sea ice — is the polar cod (Cheung et al., 2008). Hop and Gjøsæter (2013) suggest that the polar cod may remain in the Barents Sea, but would lose the ice-associated part of its life cycle, and its summer time distribution would shrink significantly. Climate change is also expected to result in higher overall production and subsequent increased catches of haddock, herring, and other boreal species (Loeng et al., 2005). Salmon abundance likely will increase in Russian waters as previously observed under warm conditions (Lajus et al., 2005) and extend its distribution to northern Svalbard. Eriksen et al. (2012) has noted recent increase in jellyfish abundance in the Barents Sea in association with warmer waters; even more jellyfish may appear as temperatures continue to increase.

Possible impacts on capelin under climate change were first explored by Huse and Ellingsen (2008). They applied a combined physical and plankton model coupled with increased temperatures based on a previous IPCC B2 scenario. In addition to a projected distribution shift northwards during summer feeding during warm periods, new capelin spawning areas were also projected to be established off Novaya Zemlya and possibly off Eastern Svalbard. Spawning would also occur earlier in the year. The potential for a shift in capelin spawning sites off Novaya Zemlya was predicted earlier by Øiestad (1990).

5.1.4.3 Marine Mammals and Seabirds

Seal species which breed and raise their young on or near the ice edge — such as the ringed seal — would experience a loss of habitat under climate change. Durner et al. (2009) suggested that within the Arctic, the greatest rate of loss of polar bear habitat over the 21st Century would occur in the Barents Sea with a rate of 6.5% per decade. Polar bears, which hunt seals near the ice edge, would have to move further north in search of prey. The earlier spring ice break-up and later fall freeze-up would force the polar bears off the ice earlier in the spring or left to deal with an unstable ice edge, leading to a general reduction in body condition. Female bears would have to go longer distances in pursuit of food leaving cubs unattended and vulnerable (Stirling et al., 1999). Walruses and whales, which rely on sea ice of a relative thickness that they can break through to create breathing holes, would benefit from a thinner ice sheet, but walruses would then encounter the problem of finding adequate sea ice to support their weight during their resting periods.

The retreat of sea ice will threaten the existence of polynyas. These areas of high productivity are known for attracting large numbers of sea birds and marine mammals. In the Barents Sea, well known polynyas occur in Storfjorden and Hinlopen on the eastern part of Svalbard and southwest of Franz Josef Land. The importance of these polynyas for the biodiversity and productivity of the Barents Sea is not known. The loss of polynyas has traditionally been a result of the open water not appearing because of closure by surrounding ice. With climate change, however, the loss would most likely be caused by a lack of sea ice that helps to define polynyas. It is unknown how this disappearance of polynyas will affect the region's biodiversity.

Species displacements may have negative impacts on seabirds and marine mammals which are used to feeding on specific prey. Fish and seabirds may alter their range in an attempt to locate suitable prey or adapt to a different food source. This could result in recruitment failure. Generally, seabirds feed only 100km from their breeding sites but this range may be extended.

It must be cautioned that not only are the atmospheric and ocean climate scenarios highly uncertain but their impacts are as well (IPCC, 2013; IPCC, 2014a, b; Howell et al., 2013). Also, climate change is just one of the global change issues that the marine environment is subjected to and other issues such as fishing or acidification will also play roles and must be taken into accounted into projections of future. Several of the projections were based on previous relationships between climate and food webs. However, it was noted by Bogstad et al. (2013) for example that we cannot count on such relationships continuing into the foreseeable future as many of them are time varying. With the high uncertainty and our lack of ability to forecast the future accurately, we must develop management strategies that are robust to unpredictable changes in stock dynamics (Howell et al., 2013).

5.2 Possible effects of ocean acidification

Along with climate change, anthropogenic emissions of carbon dioxide (CO_2) are causing acidification of the world oceans because CO_2 reacts with seawater to form carbonic acid. Due to the increased atmospheric CO_2 concentration, the average pH-value of the surface waters of the global oceans has decreased from 8.2 to 8.1 since the onset of industrial revolution. This ocean acidification is extremely rapid in northern sea areas compared to other global oceans. The reduction in pH in Norwegian surface waters is -1.3, while the global average reduction is -1.0. If acidity increases, this will significantly reduce the ability of organisms to build calcium carbonate shells and skeletons. It is expected that organisms living at high latitudes will be among the first affected by ocean acidification. Ocean acidification results in depletion of carbonate ion followed by decreased levels (saturation) of the two calcium carbonate minerals vital for shell building, aragonite and calcite. A decrease in pH and an under saturation of calcite may have fatal consequences for shell building marine life. Therefore, organisms forming shells and exoskeletons, such as mollusks, gastropods, crustaceans, echinoderms, corals and other deep-sea living creatures are of particular concern (UNEP/AMAP, 2011).

The lowest pH and the lowest saturation values of aragonite in surface waters are found at 78°N in the northeastern parts of the Barents Sea. Aragonite saturation and pH-values in this sea area are affected by the seasonal ice cover, big amounts of fresh water release due the melting processes and uptake of CO_2 through primary production. Super saturation ($\Omega Ar=1.6\pm0.3$) of aragonite and calcite occur throughout the water column, but relatively low values are found in bottom waters far north. The elevated CO_2 concentration in the deepest part of the water column is probably caused by microbial decomposition and cannot be related to anthropogenic acidification (Chierici et al., 2014).

While it is known that ocean acidification may affect metal toxicity in aquatic organisms, there is less knowledge with regard to how pH actually affects organic contaminants. Direct effects are expected to be most pronounced for phytoplankton, zooplankton, and benthos. Fish, seabirds, and marine mammals may be affected indirectly through its effects on prey, possibly making ocean acidification one of the most important anthropogenic drivers in the Barents Sea in the future (ICES AFWG, 2014).

5.3 Effects of climate change on pollution

C.F. Pettersen (Norwegian Environment Agency), J. Bytingsvik (Akvaplan-niva AS), M. Chierici (IMR), and A. Nalbandyan (NRPA)

Climate change may have a complex set of influences on both flux and fate of contaminants in the Barents Sea. Increasing temperatures, changing wind systems and ocean currents, changing precipitation regime, melting sea ice, glaciers, ice-caps, and thawing permafrost, will all affect the transport, deposition, remobilization, and flux of contaminants between air and water, as well as environmental stability, ecosystem structure, bioavailability, bioaccumulation, bio-magnification, transformation, degradation, and toxicity (Macdonald et al., 2005; Noyes et al., 2009; UNEP/AMAP, 2011; Kallenborn et al., 2012; Moe et al., 2013; Stahl et al., 2013).

5.3.1 Increasing temperatures, precipitation, ice-melt, and contaminant remobilization

Arctic temperatures are expected to increase two times faster than the global average (Trenberth et al., 2007). Hence, re-volatilization of contaminants might be a significant secondary emission source in the future. Permanent ice-cover in the central Arctic is believed to be particularly important to hinder evaporation of volatile compounds such as HCH and HCB from secondary sources such as sea water. Time series of data for POP-concentrations in air show that sea-ice retreat and rising temperatures result in remobilization of many POPs, including those with lower volatilities, into the Arctic air (Ma et al., 2011). In the Barents Sea region, increasing air concentrations of HCB have been observed at Zeppelin, Ny-Ålesund (Svalbard) since 2004, and the increase is probably caused by increasing temperatures (Hung et al., 2010; Becker et al., 2012). For example, a temperature increase of 1 °C will cause an approximately 10-15 % increase in the volatility of a semi-volatile POP such as PCBs (UNEP/AMAP, 2011).

Reductions in permafrost, snowpack, and glacial ice combined with increased erosion will result in greater release of contaminants into air and aquatic systems (Kallenborn et al., 2012). Similar scenarios are expected to occur in the Arctic, where relatively high levels of CUPs have been detected in top layers of the Svalbard glaciers (Hermanson et al., 2005; Ruggirello et al., 2010). Current use pesticides (CUPs) from the glacial top layers might be released by ice melting and run off. In Russia, melting of the permafrost has been suggested to explain the increasing levels of PCB and lead in arctic indigenous people (Chashchin, 2010). Increasing temperatures will probably result in increased degradation of contaminants in soil and sea water; increased degradation will increase the production of metabolites with an unknown toxic potency. It is expected that exploration of natural resources like minerals, oil and gas will be more feasible as the reduction of sea ice extension continues. Increasing human activity levels can also be seen as a new contaminant source (UNEP/AMAP, 2011).

Higher temperatures, changes in precipitation and shifts in the presence of snow, ice and water may also affect transport of radioactive substances and their routes in the marine environment and in the Barents Sea, in particular (AMAP, 2010). Increase in precipitation could cause faster washing out of contaminants that are currently combined in the environment. Melting of sea ice could release radioactive substances trapped in the ice into the marine environment (Olseng et al., 2009). A reduction in ice cover, especially in summer, will lead to less significance for sea ice as a transport medium for radionuclides from atmospheric fallout and from incorporated sediment. This is likely to lead to a reduced export and a larger fraction of the radionuclides remaining within the Arctic Ocean. For radionuclides imported with water from the Nordic Seas, the anticipated increase in vertical mixing and convection in the Arctic Ocean could lead to an increased fraction of radionuclides in the mid-depth water. This would increase residence time in the Arctic, compared to surface transport (AMAP, 2010).

5.3.2 Effect of climate-induced changes in wind and circulation on transport of contaminants

Changes in ocean circulation and in the sea ice may affect the pathways of radioactive substances in the marine environment. It is expected that movement t both into and out of the Barents Sea may become more rapid than today (AMAP, 2009). The enhanced volume inflow to the Barents Sea anticipated for the 21st century increases the exchange between the shelves and the deep basins. This exchange is expected to be further enhanced by intensified wind-induced upwelling and down-welling at the shelf break, partly due to stronger winds and partly due to a reduced period of ice cover in the season (Carmack and Chapman, 2003; ACIA, 2005). These processes are relevant for the transport of radionuclides entering with Atlantic Water from the south and those which enter the shelf directly, stemming for example from runoff or the dump sites in the Kara Sea (JRNC, 1993; IAEA, 1999).

Extreme weather like serious flooding in areas where deposited pollutants stored in soil has resulted in remobilization and release of contaminants into rivers and air in southern European countries (Kallenborn et al., 2012). Similar scenarios might be expected also in northern areas and has been predicted to be of significant size for instance for the rivers in Northern Russia.
Due to increased storm activity and more open water, intensified vertical mixing may lead to an increased re-suspension of sediments, with consequences for the remobilization of radionuclides with sediments or from sediments into the liquid phase (Schiedek et al., 2007). Important areas in this context are the dump sites in Novaya Zemlya bays (Harms and Povinec, 1999) and former nuclear test sites like Chernaya Bay (Smith et al., 2000). Mobilization of sediment bound radionuclides also depends on the ambient salinity (Oughton et al., 1997).

5.3.3 Impact(s) of climate change on bioaccumulation and biomagnification

It has been concluded that climate change parameters will impact the toxicology and toxic effects in biota (Noyes et al., 2009). Changes in food webs related to increasing temperatures have already been reported from some Arctic areas. This may alter trophic structures and biodiversity, food sources, migratory patterns, and hence influence the bioaccumulation and biomagnification of contaminants in food webs and the biological transportation of contaminants between latitudes (UNEP/AMAP, 2011).

Attempts to predict climate change-induced alterations in bioaccumulation of contaminants in the Barents Sea food web show that bioavailability may be influenced by the extent of the primary production (Borga et al., 2010). The amount of particulate organic carbon (POC), representing primary production and terrestrial input in the marine environment, can be important for the actual fate of hydrophobic chemicals (Amitage and Wania, 2013). Also studies on animals support the notion that climate variability may impact the transport and fate of POPs, and hence, modulate the temporal trends of POPs in the Arctic environment (Bustnes et al., 2010).

Food availability may become scarce for some species as a result of increasing temperatures followed by asynchronous spatial or temporal patterns between predators and prey. Some species are expected to suffer from starvation. It is reported that eiders at high latitudes metabolize more lipids and release more contaminants to blood stream than eiders from more southern latitudes during incubation (Bustnes et al., 2012). Also polar bears in the Barents Sea are expected to have periods of starvation and increased contaminants release from fat reservoirs as already observed in the Hudson Bay population where climate effects is said to be one step ahead of the European Arctic (UNEP/AMAP, 2011). The immune system has also been shown to be sensitive to contaminant exposure (Bustnes et al., 2004; Lie et al., 2004; Lie et al., 2005), and in environments where new and more pathogens are expected, the situation might represent a serious future challenge.

The bioavailability of radionuclides in the marine environment is likely to be subject to the effects of climate change (AMAP, 2010). The radioactive substances that could be released into the marine environment as a result of ice melting could become bioavailable for the marine organisms. Changes in temperature may lead to changes in turnover rates of radionuclides in cold-blooded animals such as fish. More research is needed to study relationships and combined effects between diverse climatic, physicochemical and biotic factors that influence the uptake and bioaccumulation of radionuclides by marine species (AMAP, 2009).

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6 Adopting and Adapting an Ecosystem Approach to Management

J.R. Hansen (NPI), O. Korneev (SMG), M.M. McBride (IMR), and J.E. Stiansen (IMR)

6.1 Supporting Legislation

6.1.1 Fishery enforcement agreements

Fisheries and other harvesting are drivers that have major impact on the Barents Sea ecosystem. These activities have a long history dating back to the early 17th century when large scale whaling activity started. In centuries which followed, whaling and other hunting led to the near extinction of several whale stocks and other marine mammals such as bowhead whales (Balaena mysticetus), North Atlantic right whales (Eubalaena glacialis), and walruses (Odobenus rosmarius). Open ocean fisheries in the Barents Sea began at the beginning of the 20th century with development of trawling technology. At present there is an ongoing multinational fishery in the Barents Sea using different fishing gears such as trawls, longlines, and purse seines targeting several species. The largest exploited fish stocks, however, are Northeast Arctic cod, haddock, and saithe. These three species are currently harvested within sustainable limits and have full reproductive capacity. While smaller stocks including golden redfish and coastal cod are believed to be overfished. Damage to benthic organisms and habitats from trawling has been documented. Overcoming these problems and furthering our understanding of the effects of fisheries within an ecosystem context are important challenges for management.

Until the 1960s, there were few fishery regulations outside national borders. In later years, and especially after the introduction of Exclusive Economic Zones (EEZ) —prescribed by the United Nations Convention on the Law of the Sea — a series of catch and technical regulations has been introduced to ensure sustainability and long-term yield in Barents Sea fisheries.

An important element of these measures is to ensure the fishing fleet’s compliance to management regulations. At present, decisions made by Joint Russian-Norwegian Fishery Commission have established a tight co-operation — between inspectors from the coast guard and other enforcement authorities —to inspect fishing vessels and the gears used. Also, work is ongoing to harmonize technical regulation of fishing gears used by Russian and Norwegian fishing vessels operating in the Barents Sea. There is additional cooperation between Russian and Norwegian authorities regarding a wide range of other measures such as satellite tracking of fishing vessel, control of landing fish products, etc. Focus has been placed to limit problems related to Illegal, Unreported, and Unregulated (IUU) fishing and trans-shipment of fishery products within the Barents Sea region. Another important issue is to develop and implement measures to reduce discard of catches.

The Accounts Chamber of the Russian Federation and the Office of the Auditor General in Norway conducted in 2006-2007 an audit of Management and Control of Fish Resources in the Barents Sea and the Norwegian Sea. This audit was performed in parallel in the sense that common audit questions and audit criteria were defined and the same outline was used for the reports. The two audit reports were written separately and on the basis of independent information.

Audit topics included:

- Assessment of the scope of illegal and unregistered cod fishing
- Implementation of decisions taken by the Fisheries Commission
- Resource control
- Sanctions for violations of acts and regulations
- Distribution and filling of quotas
- Analysis of the execution of the joint Norwegian-Russian research programmes

Based on these parallel investigations, a joint memorandum was signed by Auditors Generals of both countries on 18 June 2007. The memorandum presents common assessments and summaries of national results.

Findings from the 2007 audit led both parties to conduct follow-up audits during 2008-2010. The follow-up audit showed that the extent of illegal and unregistered overfishing of cod in the Barents Sea was reduced considerably — from an estimated 100,000 tonnes in 2005 to zero proven cases in 2009. Since the survey period for the 2007 audit, enforcement was strengthened through increased regulatory controls and the use of more advanced technical tools.

6.1.2 Agreements concerning pollution

International agreements and conventions, both globally and regionally, are of major importance to control and reduce pollution of the Barents Sea. These agreements include regulation of activities and restrictions or bans on use of hazardous substances. One of the most important is the 1982 United Nations Convention on the Law of the Sea, which both Norway and Russia have adopted. It entered into force in 1994 and lays down fundamental international rules for all maritime activities. It constitutes the overall legal framework for activities in and management of the Barents Sea. The convention establishes rights and duties that apply to both Norway and Russia as coastal states regarding protection of the environment, jurisdiction over maritime transport, and utilization of living marine resources as well as petroleum- and energy resources.

In accordance with the Law of the Sea, the states have a duty to preserve and protect the marine environment. To reach this goal the states should implement necessary measures in accordance with the Convention. States are especially invited to cooperate both globally and regionally when formulating international rules, standards, and recommendations with regard to the protection of the marine environment. In the North-East Atlantic, there is active regional cooperation under auspices of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR). OSPAR’s mission is to conserve marine ecosystems and safeguard human health in the North-East Atlantic by preventing and eliminating pollution, by protecting the marine environment from adverse effects of human activities, and by contributing to the sustainable use of the seas. OSPAR's Region 1 covers Norwegian and Russian parts of the Barents Sea. Thus far, the Russian Federation is not a party to OSPAR.

One of the first global conventions to protect the marine environment from human activities is the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter from 1972, also known as the 'London Convention'. Its objective is to promote the effective control of all sources of marine pollution and to take all practicable steps to prevent pollution of the sea by dumping of wastes and other matter. Norway and the Russian Federation are both parties to this Convention.

As long-range transport of persistent organic pollutants (POPs) and certain metals from the rest of the world is the most important pollution-related pressure on the Barents Sea, international conventions and agreements concerning reduction in use and bans of hazardous substances are of major importance. The Convention on Long-range Transboundary Air Pollution and the Stockholm Convention on persistent organic pollutants are important global conventions regulating and/or banning use of the most hazardous POPs.

In Russia, responsibility for control and protection of the environment is given to legislative authorities at all levels, from the Duma to local municipalities. Executive power is also distributed from the federal to the regional level. Legislative authorities develop legal acts to improve the ecological situation, based on their own initiatives or input from the executive branch. Generally, all Russian federal laws in effect to protect the environment comply with respective international conventions, including the Law of the Sea that was ratified in 1984. Since 2008, the Ministry of Natural Resources and Ecology has been the single federal organ with executive power to develop normative acts, prescribe maximum-allowed levels of pollution and biota, and issue control rules for pollution and damage estimates. Under the umbrella of the Ministry of Natural Resources, there are the several organizations to carry out nature protection functions.

The Joint Russian-Norwegian Environmental Commission has and continues to promote: increase general understanding of the extent and effects of pollution in the northern areas; strengthen collaboration regarding control, monitoring, and prevention of pollution to the environment and the handling of waste. Under the umbrella of the Environmental Commission, a joint Norwegian-Russian Expert Group was established in 1992 to ensure nuclear safety and radiation protection in the north (Hønnland and Rowe, 2008). To strengthen co-operation between Norway and Russia in the nuclear safety arena, the Norwegian government's Nuclear Action Plan was initiated in 1995 and revised in 2008. For its execution, the Norwegian Radiation Protection Authority serves as the directorate for the Ministry of Foreign Affairs. The Nuclear Action Plan contributes to reduce the risk of accidents and pollution from nuclear installations in Northwest Russia and prevent radioactive and fissile material from going astray. It is the most important management tool of the

Norwegian authorities in their nuclear safety efforts with Russia. Nuclear safety co-operation is built on several bilateral collaboration agreements (see www.nrpa.no/en/). The Norwegian Radiation Protection Authority closely collaborates with a number of Russian governmental agencies and supervisory authorities in the area of nuclear safety, radiation protection, preparedness, and environmental monitoring.

Long-range transport of pollutants — especially persistent organic pollutants (POPs), radionuclides, and certain metals — is currently the most important pollutant-related pressure on the Barents Sea. This is also the main source for accumulation of POPs in arctic top predators, and the main reason that environmental goals are not met (AMAP, 2010). To ensure that the Barents Sea remains clean and species rich in the future, knowledge of transport routes and changes in transport routes due to e.g. climatic change, regulating the use of new chemicals is important.

6.1.3 Agreements regarding maritime transport

Shipping is an extensively international industry. Therefore, global legislations, conventions, and standards which regulate shipping are desirable and play an important role to harmonize the regulations across nations. Major international organisations which contribute to regulations are: IMO (International Maritime Organisation), ILO (the UN's international workers organisation), and EMSA (European Maritime Safety Agency). Regional initiatives are also helpful, such as the Arctic Marine Shipping Assessment conducted by the working group PAME (Protection of the Arctic Marine Environment) under the Arctic Council.

The International Maritime Organization (IMO) protects the interests of flag states by providing uniform global technical standards for ships and crews, although the interests of coastal states are also safeguarded. In response to accidents in European coastal waters, the EU has played a more active part in this work, and the interests of coastal states have been given more weight. The EU has also expedited implementation of international legislation by adopting it as community law. This has influenced the work of the IMO, which has adopted a number of global conventions to protect the marine environment from the negative impacts of maritime transport. Presently, the most important of these conventions are the International Convention for the Safety of Life at Sea (SOLAS, 1974) and the International Convention for the Prevention of Pollution from Ships (MARPOL, 1973/78). Requirements under these conventions are under continuous revision; one example is the adoption of an accelerated phase-out schedule for single-hull tankers. In October 2001, the IMO also adopted a new convention on control of harmful antifouling systems; in 2004 a new convention was adopted to regulate ballast water intake, discharge, and management. Another example is the Ballast Water Convention approved in February 2004, which Norway has ratified; this convention compels signatory nations to ensure, by 2016, that all ballast water in both old and new ships is treated before being discharged. By 2012, all new ships were required to treat their ballast water; prior to 2012, all vessels were required to discharge their ballast water in the open sea.

As part of its maritime safety and antiterrorism measures, the IMO's Maritime Safety Committee initiated establishment of long-range vessel identification and tracking systems

(LRIT); design of these systems has not yet been finalised. Such systems can also be used to supplement maritime safety and oil spill response measures, just as land-based AIS (Automatic Identification System) networks can be used to identify traffic in near-shore waters.

Cooperation between Russian and Norway to protect against oil pollution in the Barents Sea has been ongoing for more than 20 years. It is built upon an “Agreement between the Kingdom of Norway and the Russian Federation concerning Cooperation to Combat Oil Pollution in the Barents Sea (1994); and a Memorandum of Understanding (2006). The Joint Norwegian-Russian Contingency Plan for the Combatment of Oil Pollution in the Barents Sea was signed in Moscow on 28th of April, 1994. The cooperation has had practical joint activities during which oil pollution protection authorities from both countries have gained experience through conducting joint exercises both in Norway and in Russia. Earlier these joint exercises were organised every other year; in recent years such exercises have been conducted at least once each year. The Norwegian Ministry of Fisheries and Coastal Affairs, the Norwegian Environment Agency, the Norwegian Coastal Administration, and the Ministry of Transport of the Russian Federation — represented by its oil pollution protection unit, the Murmansk Basin Emergency-and-Salvage Department — are the main responsible institutes in this cooperation. Joint exercises include both search-and-rescue and combating oil spills.

6.2 Joint Norwegian-Russian Fisheries Commission

Major stocks supporting fisheries in the Barents Sea are also shared stocks between Russia and Norway. A key challenge is to create the basis for an optimal and effective management regime for these shared fishery resources, including rational harvesting of cod and other important stocks. During the late 1970s, cooperation on management of shared fish stocks was instituted through the Joint Norwegian-Russian Fisheries Commission (JNRFC), formally established in 1975. This long-standing bilateral cooperation is of critical importance to ensure sustainable fisheries in the Barents Sea. Its responsibilities include deciding: management strategies; levels of total allowable catch (TAC); TAC allocation between Russia and Norway; and technical measures regulating use of fishing gears; and implements systems to ensure that the fishing industry adheres to regulatory decisions. JNRFC stipulates reciprocal access to fisheries within national zones, and quota exchanges for shared and national stocks; it also decides catch quotas for third party fisheries conducted by non-coastal states.

Stocks are currently assessed through the International Council for the Exploration of the Sea (ICES) which provides scientific advice and contributes to sustainable management. JNRFC uses this advice to decide safe fishing quotas for Russia, Norway, and third-party countries. Annual quota agreements are also used to establish the effective regulatory measures, such as criteria for closures of fishing areas related to excessive capture of juvenile fish, or use of sorting grids in trawl fisheries.

JNRFC sets fishing quotas according to rules established in the management plan for Northeast Arctic cod; this plan is designed to keep cod fishing mortality at a stable level that contributes to stability and predictability within the industry. Quotas for joint stocks of Northeast Arctic cod, haddock, and capelin are determined on the basis of agreed-upon, sustainable, management strategies.

TACs established through JNRFC are based on recommendations provided by ICES, at meetings where both Norwegian and Russian scientists participate; these scientists carry out joint surveys and other types of data collection activities. After TACs and their allocation have been decided, national management bodies — Federal Bureau of Fisheries in Russia, the Ministry of Fisheries and Coastal Affairs and the Directorate of Fisheries in Norway— further divide national TACs relative to fleet groups, individual vessel quota; they also decide which gear types may be utilized, etc.

6.3 Russian Integrated management planning

Historically, management by sector and uncoordinated plans for development have lowered effectiveness of some types of ocean use activities; this has led to latent conflicts and negative ecological consequences for marine resources in Russia.

Hence, a Strategy for the Development of maritime activities of the Russian Federation for the period up to 2030 was approved by the Federal Government in December, 2010 (№ 2205-p); this Strategy guides the development of various marine use activities under an "integrated management of marine resources" umbrella. This Strategy incorporates a number of tools to better utilize and develop marine resources, including:

- Government directives specifying tasks to develop a pilot project for the integrated management of natural resources in the Arctic seas and to implement it in the Russian zone of the Barents Sea; and
- Research and development for a pilot project on marine spatial planning to support optimal utilization of marine resources in the Russian zone of the Barents Sea, while maintaining a safe level of biodiversity in the ecosystem. This project was completed in May 2015, and involved Joint Stock Company Sevmorgeo, PINRO, MMBI, AARI, VNII Ecology, and WWF-Russia; it was based on 2 key documents:
    1) Norwegian integrated marine management plan for the Barents Sea (2006) https://www.regjeringen.no/globalassets/upload/md/vedlegg/stm200520060008en_pdf.pdf; and
    2) Guidelines for Marine Spatial Planning of International Oceanographic Commission UNESCO (2009). http://unesdoc.unesco.org/images/0018/001865/186559e.pdf.

Implementation of the above-mentioned documents has led to the creation of the Integrated Marine Management Plan for the Russian Zone of the Barents Sea. Key components of the plan include:

- Evaluating goals and tasks of the Plan
- Estimating temporal (2020-2030) and spatial limits for the Plan

- Determining current and predicted state of the ecosystem — abiotic (air, water and sediment) and biotic (from zooplankton to marine mammals and seabirds) components
- Estimating current and future development of anthropogenic maritime activity (ports, shipping, fishery, aquaculture, oil and gas development, municipal waste water treatment plants, navy activity, protected areas, tourism, recreation, pollution)
- Mapping ecosystem parameters and anthropogenic activity in ArcGIS with subsequent evaluation of the conflicts between sectors as well as between the anthropogenic activities and integrated seasonal levels of biodiversity of two trophic levels (plankton-benthos and fish-seabirds-marine mammals)
- Suggestions and recommendations to;
  - Improve the Russian environmental legal framework
  - Implement ecological boundaries for fishing, shipping, and oil and gas related activities
  - Develop protected areas, including measures for protection of rare and vulnerable species
  - Integrate monitoring of Plan implementation, including the comprehensive monitoring of the Barents Sea ecosystem state and monitoring of industry compliance to ecological boundaries.

Analyses of sector-related strategic documents for current and future (2020-2030) economic development indicate that the main impacts on the Barents Sea ecosystem in the Russian zone will be through the rapidly increasing maritime shipping industry. There are plans to increase annual shipping along the Northern Sea Route up to 63,700 thousand tons by 2020. Given that freight traffic was only 1,160 thousand tons in 2013, this projects an increase of more than 54 times (+ 5,391.38%). A substantial increase in cargo turnover is planned for existing ports (Murmansk, Arkhangelsk, and Vitino) in addition to the construction of new ports at: Teriberka; Indiga; Amderma; Linahamari; MSLP "Prirazlomnaja"; Varandey oil terminal in the Barents Sea; as well as Sabetta, New Port, and Arctic oil terminals in Ob Bay of the Kara Sea. These plans are expected to result in overall increased shipping activity in Russian waters of the Barents Sea: up to 4 times more by 2020; and up to 6.5 times more by 2030.

Development of oil and gas activity is estimated according to operator's license agreements up to 2024 for the relevant license areas. Under these license agreements, there are no plans to introduce new oil and gas wells in the area during the period up to 2024. The main activity in licensed areas will be seismic: 2D – 48,200 linear km; 3D - 21,650 square km, prospecting (drilling 27 wells); and exploratory (drilling 7 wells).

In coming years, a significant increase in production of commercial aquaculture in the coastal zone of Kola Peninsula is anticipated. Thus, according to the Strategy for the Development of the Murmansk region, production volume is expected to increase from 16.3 thousand tons in 2012 to 98.9 thousand tons in 2025, i.e., 6 times.

An important component of the management plan was to define areas with spatial conflicts between anthropogenic activities and integrated seasonal biodiversity levels. It was determined that the biodiversity maxima are typically observed during the 3rd quarter (July - September) and localized along the coast of Kola Peninsula, in the Pechora Sea, and along the Novaya Zemlya archipelago (Figures 6.3.1 and 6.3.2).

Based on studies conducted, a number of regulatory suggestions and recommendations have been developed for integrated ecosystem-based management in the Russian zone of the Barents Sea.

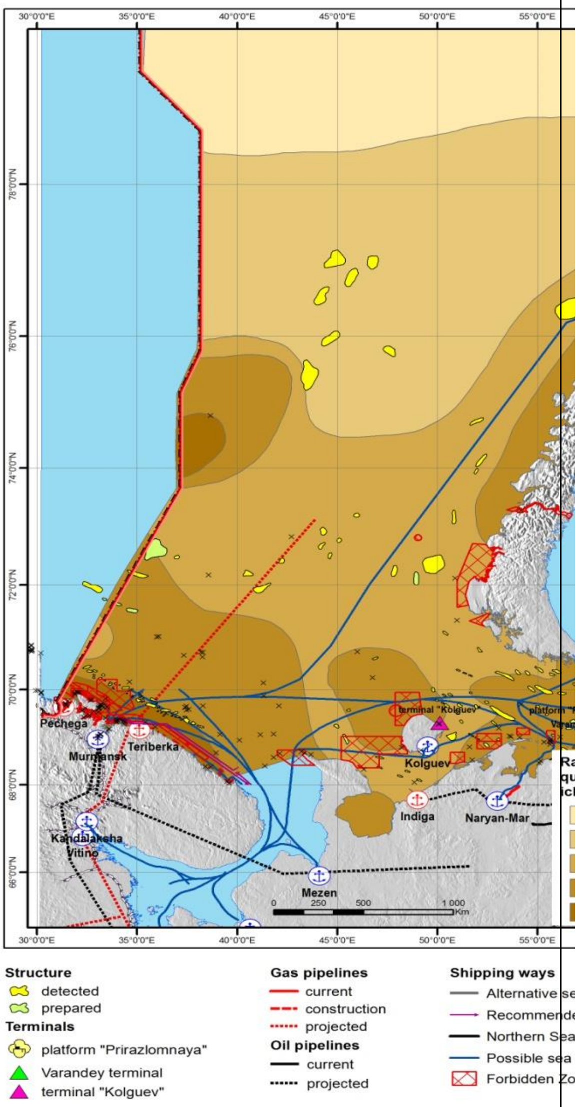

Figure 6.3.1. Anthropogenic impact on biodiversity of plankton and zoo-benthos for summer season (July-September).

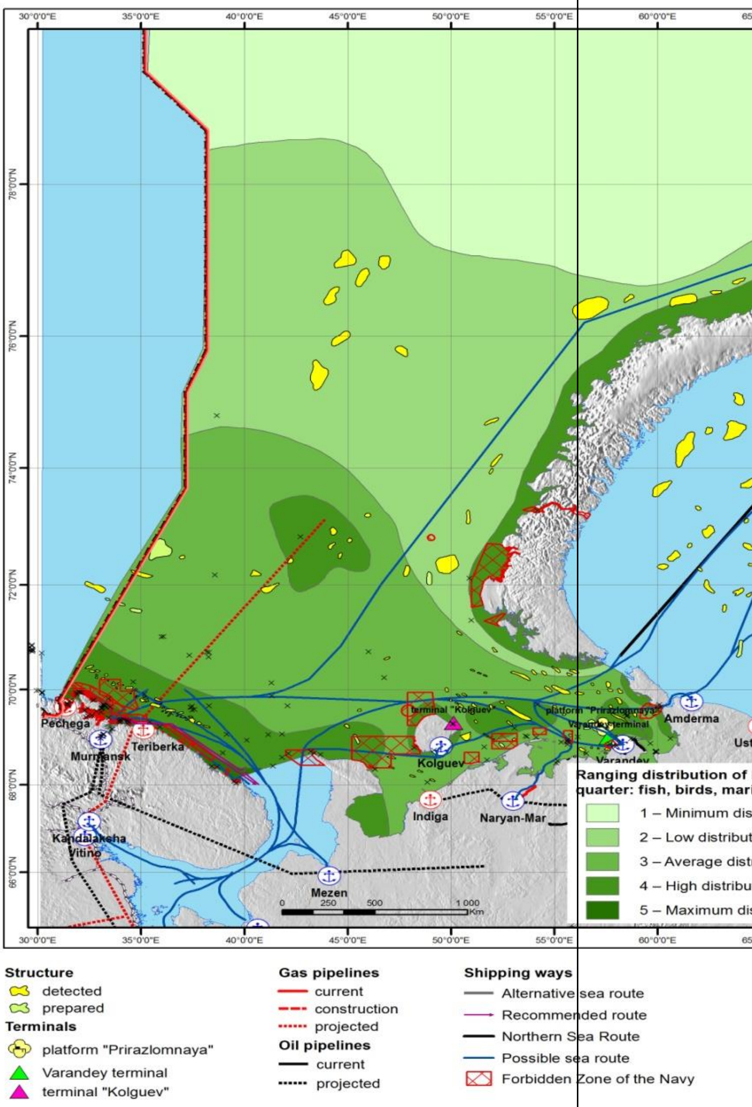

Figure 6.3.2. Anthropogenic impact on biodiversity (fish, birds and mammals) for summer season (July-September).

Maritime traffic

1. For marine protected areas, situated:
   a. In the territorial sea; it is necessary to introduce a unilateral ban on free navigation of ships through a binding document for navigators "Notice to Mariners";

   b. In the exclusive economic zone (EEZ) areas where sea ice is present "for most of the year", a unilateral ban on free navigation of ships should be introduced;
   c. In other EEZ areas, a request to IMO should be prepared to impose the same ban.
2. Considering the anticipated sharp increase in the volume of shipping in EEZ, the following transport routes are recommended:
   a. Main shipping along the Northern Marine Route should be conducted via northern option (above Novaya Zemlya archipelago);
   b. In the Pechora Sea above Kolguev Island navigation routes should be – along 70 N latitude;
   c. Shipping through Yugorskiy Shar should be forbidden, at least during the 2nd and 3rd quarters.

Oil and gas

1. Seismic investigations should be conducted during the 1st and 2nd quarters and at the end of the 4th quarter in areas with biodiversity maxima;
2. Prospecting and exploratory drilling should only be conducted with a 0 discharge policy;
3. hydrocarbon extraction should only be conducted with a 0 discharge policy;
4. Oil offloading on marine trans-shipment terminals should be carried out with mandatory recovery of hydrocarbon emissions from the tanks of tankers (both large and small "breathing").

Commercial fisheries

1. It is necessary to improve short-term forecasting of fish stock abundance;
2. Provide fishing vessels with modern search equipment to select optimal fishing strategies for specific areas to minimize the impact on non-target species, juveniles, and benthic habitats;
3. Develop new technologies for bottom trawling;
4. Further develop the Russian long-line fishery;
5. Reduce IUU fishing, and recycle residual IUU catch;
6. Introduce specific regulations for snow crab fisheries in the Russian zone;
7. Create a “Responsible Fisheries Fund” as a tool to facilitate interactions between the State, fishermen’s associations, and nongovernmental organizations.

Protected areas

1. Preserve existing biodiversity in marine ecosystems by establishing new protected areas: marine reserves of West and East Murman; Gusinaya Banka; Czechskaya Guba; Ostrov Kolguev; Bolshezemelskiy Zapovednik; and Biosphere Reserve of Nenets zapovednik;
2. Change the status of "Vaigach" from regional reserve to a federal reserve through the accession of Yugorskiy Shar straight.

To implement regulations for marine spatial planning and execute its strategic environmental assessment into Russian legislative practice, detailed proposals for the following federal laws are currently under review:

- "On the governance of maritime activity in the Russian Federation"
- "On the marine planning in the Russian Federation"
- "On Amendments to the Federal Law”
- "On Environmental Protection" and other legislative acts of the Russian Federation" to implement provisions of the Strategic Environmental Assessment.

To implement the project “Integrated ecosystem-based management” in Russia, the following steps are necessary:

- Introduce Strategic Environmental Assessment (SEA) procedures or Environmental Impact Assessment (EIA) for plans to develop different branches of the economy in specific marine areas;
- Implement provisions of the Federal Law "On the strategic planning in Russia" to develop cross-sectoral strategies for specific marine areas;
- Develop national regulatory and methodological documents regulating the implementation of marine spatial planning (MSP);
- The use of state Unified Information System on World Ocean (ESIMO) as a basis for marine spatial planning (MSP) mapping projects.

6.4 Norwegian Integrated management plan

The summary presented below is based on “Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands” (Report No. 8 (2005–2006) to the Storting. Russian version: Комплексное управление морской средой Баренцева моря и морских районов, прилегающих к Лофотенским островам (план управления). Доклад правительства Стортингу No 8 (2005–2006).

The Government’s proposal was presented in the white paper: Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands (Report No. 8 (2005–2006) to the Storting). This was the first integrated management plan developed for a Norwegian marine area, and was debated in the Storting in spring 2006. The 2006 white paper states that the management plan will be a living document and will be revised at regular intervals. The Government would: 1) regularly assess the need to follow up and update the management plan; and 2) assess the overall need for new measures to achieve the plan’s goals, based on the status reports to be submitted from 2010 onwards.

The purpose of the management plan is to provide a framework for the sustainable use of natural resources and goods derived from the Barents Sea and the sea areas off the Lofoten Islands (subsequently referred to as the Barents Sea–Lofoten area) (Figure 6.4.1) and at the same time maintain the structure, functioning, and productivity of the ecosystems of the area. The plan is intended to clarify the overall framework for both existing and new activities in these waters. The Government considers it very important to encourage broad-based and varied industrial development in Northern Norway. It is, therefore, important to facilitate the co-existence of different industries: particularly fisheries; maritime transport; and petroleum extraction. The management plan highlights issues where further work is required to ensure that these industries continue to co-exist effectively. The plan is also instrumental to ensure that business interests, local, regional and central authorities, environmental organisations and other interest groups all have a common understanding of management goals for the Barents Sea–Lofoten area. The plan focuses on the environmental framework for sustainable use of this sea area. Spin-off effects on onshore business and industry in Northern Norway and on value creation in the region are therefore not treated here. The Government will initiate separate processes to deal with these issues at a later date.

The management plan emphasises that special precautions are needed to protect certain areas covered where the environment and natural resources are considered to be particularly valuable and vulnerable. Based on scientific assessments, these areas are recognised to be of great importance for biodiversity and biological production in the entire Barents Sea–Lofoten area. Adverse impacts to these areas might persist for many years. Important criteria used to identify these areas were that they support: high biological production; high concentrations of species; and/or endangered or vulnerable habitats. Additional important criteria included their function as key habitats for either: endangered or vulnerable species; species for which Norway has a special responsibility; or internationally or nationally important populations of certain species (year round or seasonal). Vulnerability was assessed with respect to specific environmental pressures such as oil pollution, fluctuating in food supply, and physical damage. Vulnerability varies from one time of year to another.

Areas identified as particularly valuable and vulnerable include: between the Lofoten Islands and Tromsøflaket Bank; Eggakanten; a zone off Finnmark County stretching 50 km outwards from the baseline; the marginal ice zone; the polar front; the coastal zone of Bjørnøya and the rest of Svalbard (Figure 6.4.2). These areas represent key spawning grounds and egg and larval transport zones for commercially important fish stocks in the Northeast Atlantic, such as Northeast Arctic cod and herring. Several of these areas are also important as breeding, moulting, or wintering areas for internationally important seabird populations, such as the lesser black-backed gull (subspecies *Larus fuscus fuscus*), Steller's eider, and Atlantic puffin. In addition, areas identified include valuable and vulnerable habitats for communities of benthic fauna such as cold-water corals (the largest known cold-water coral reef is off Røst in the Lofoten Islands) and sponges.

Figure 6.4.1. Management plan area of the Barents Sea and the waters off Lofoten. Source: The updating of the management plan for the marine environment in the Barents Sea and the waters off the Lofoten Islands ((Report No. 10 (2010–2011) to the Storting). Cartography: Norwegian Polar Institute 2011. Source for depth data: IBCAO.

Figure 6.4.2. Especially valuable and vulnerable areas in the Barents Sea-Lofoten (green areas). Source: The updating of the management plan for the marine environment in the Barents Sea and the waters off the Lofoten Islands ((Report No. 10 (2010–2011) to the Storting). Cartography: Norwegian Polar Institute 2011. Source for depth data: IBCAO.

The Government has attached great importance to obtaining a sound scientific basis for the management plan. Information was compiled on environmental conditions, commercial activities in the Barents Sea–Lofoten area, and social conditions in North Norway to provide a common factual basis for impact assessments. Impact assessments have been carried out for human activities which may affect the state of the environment or the natural resource base in this area, including: fisheries; petroleum extraction; maritime transport; and other potential commercial activities.

Nevertheless, there are knowledge gaps to understanding the varying physical, chemical, and biological processes which determine marine ecosystems. In response to gaps which have been identified, the Government intends to introduce a better-coordinated monitoring system to assess ecosystem status; it will use indicators, reference values, and action thresholds to provide a basis for more systematic evaluation of ecosystem trends in the area.

Norwegian authorities implemented the plan with ambitious goals for future management of the Barents Sea–Lofoten area to ensure that: the state of the environment is maintained where it is good; and that where problems have been identified, the state of the environment will be improved. One goal is to ensure that activities in particularly valuable and vulnerable areas are conducted in a way that does not threaten ecological functioning or biodiversity. Populations of endangered and vulnerable species, and species for which Norway has a special responsibility, are to be maintained or restored to viable levels. Unintentional negative impacts on such species as a result of activities in the Barents Sea–Lofoten area are to be reduced.

The management plan acknowledges that there are challenges to be dealt with, particularly with regard to long-range transport and trans-boundary pollution. Another central issue is the risk of, and response to, acute oil pollution. The plan emphasises environmental risks associated with acute pollution from maritime transport, and advises a cautious approach to the expansion of petroleum activities. Based on an evaluation of the areas that have been identified as particularly valuable and vulnerable, an assessment of the risk of acute oil pollution, and an evaluation of interactions with the fisheries industry, a new framework has been established for petroleum activities in these areas (NEA, 2011).

The plan reinforced efforts to safeguard biodiversity, with special emphasis on sustainable harvesting in the Barents Sea. This includes consideration of the fact that trawling with heavy bottom gear can: damage benthic habitats; result in changes in benthic communities; cause unintended bycatch of seabirds and negatively affect their food supply.

Internationally, the Barents Sea has been identified as a Large Marine Ecosystem (LME). Accordingly, the plan encourages close cooperation with Russia to ensure an integrated management regime for the entire Barents Sea. To ensure that the environmental state remains satisfactory, agreed-upon environmental assessments needed, as well as high regulatory standards for all anthropogenic activities in the entire area. This focuses the efforts of working groups under the Joint Norwegian-Russian Commission on Environmental Protection.

The Norwegian Government wishes to ensure that the management plan is implemented and adhered to systematically, but also remains adaptable relative to new knowledge, changed activity levels, trends in environmental status, and other developments.

A new report has been issued: The updating of the management plan for the marine environment in the Barents Sea and the waters off the Lofoten Islands (Report No. 10 (2010–2011) to the Storting). The process is underway to issue another updated plan in 2020 that should remain in effect through 2040. The Government will ensure that interest groups affected are given an opportunity to play an active role in this process.

6.5 Future needs for monitoring and evaluation

Continued careful monitoring and evaluation of essential components will be necessary to determine the changing status of the Barents Sea ecosystem and the effectiveness of management actions — whether or not management strategies improve ecosystem services and sustainability. Monitoring objectives for ecosystem-based fisheries management (EBFM) and integrated ecosystem assessment (IEA) will likely include data collection to support:

ecosystem models which can simulate major ecosystem functioning and energy transfer in the food web; risk analyses; multispecies models; stock assessment models; assessing water quality/fish habitat; estimating total fishery removals; evaluating strategies for effective research and management of its natural and mineral resources; etc.

Two types of monitoring are particularly important to IEAs:

1. Trend monitoring over time to detect change in the status of an ecosystem component; these observations are typically not aimed to evaluate management actions, but may prove useful in this context. Trend monitoring focuses on indicators of ecosystem status; and
2. Effectiveness monitoring to evaluate whether specific management actions have had the desired effect. Effectiveness monitoring focuses on changes in perceived threats and links threat reduction to changes in the status of key ecosystem components. Thus, effectiveness monitoring requires the observations of threats as well as the ecosystem component(s) targeted by specific management action(s) (Levin et al., 2014).

Evaluation of ecosystem status uses data from trend monitoring to assess condition or status of particular ecosystem components. In contrast to status evaluation, evaluations to measure management effectiveness are linked to discrete management actions and to effectiveness monitoring. Two types of effectiveness evaluations have been described:

1. Impact evaluations to determine how well a particular project performed;
2. Effectiveness evaluation to systematically evaluate and adapt management actions. Successful IEAs will evaluate the effectiveness of management actions and provide information to managers so they can adjust actions, as needed.

Fortunately, there is a considerable amount of information relevant to meeting EBFM objectives that is already being collected in the Barents Sea within ongoing monitoring programmes. Nevertheless, some additional monitoring will be needed as routine data products to describe ecosystem structure, function, and status are developed for IEA. Specific monitoring programmes should be defined in relation to chosen indicators of ecosystem condition.

Combined reporting mechanisms

Many scientists from both Russia and Norway representing 13 institutions have contributed expert knowledge to develop this report. In addition, several hundred ship personnel, technicians and scientists have participated in collecting data which form the basis of this knowledge and present a broad overview of the ecosystem status and functioning. In the future it is recommended that full updates, such as this one, be carried out every three year. Minor updates of the most variable ecosystem components (e.g. climate, plankton, fish, and fisheries) should be carried out annually. It is also recommended that a three-year cycle be followed to update the status of the most important pressures and human activities in the Barents Sea.

Within the Norwegian-Russian collaboration, a plan has been developed for joint monitoring of the Barents Sea that includes 22 environmental indicators. These data will support future updates of this report, and will be important to evaluate environmental status, and recommend appropriate management options.

Future information needs to meet the above-mentioned objectives of EBFM and IEA of the Barents Sea should be achieved through:

1. Further development of joint Norwegian-Russian monitoring and evaluation programmes, and through collaboration to continue and improve existing mechanisms for ecosystem status reporting
   a. Increased effort on IEA-relevant monitoring
   b. Strengthened coordination of joint Norwegian-Russian monitoring of the Barents Sea
   c. Further development of the framework for joint reporting status on the status of the Barents Sea ecosystem.

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7 Summary and conclusions

M.M. McBride (IMR), J.R. Hansen (NPI), O. Korneev (SMG), and O. Titov (PINRO)

The Norwegian-Russian environmental status report on the Barents Sea ecosystem is a project under the Joint Norwegian-Russian Commission on Environmental Cooperation, and is part of the Commission's work programme for 2013-2015. This work is carried out within the Marine working group and represents an update of the common environment status first published in 2009, at www.barentsportal.com. More than 130 experts from a total of nine Russian and 22 Norwegian management and research institutions have participated in the preparation of the report, and the work has been organized in 13 expert groups. The project has been led by institutions in Russia (SEVMORGEO and PINRO) and Norway (NPI and IMR). Expert groups began their work in March 2015, and the report is based on data collected in 2013-2014 and earlier.

The report gives descriptions and status of the most important abiotic and biotic components of the ecosystem, and the human activities and their influences based on knowledge and monitoring from Norwegian, Russian and other scientific institutions. This report strengthens the knowledge base for the development of an ecosystem-based management plan for the Russian part of the Barents Sea and for the further development of management plan for Norwegian parts of the Barents Sea.

The Barents Sea ecosystem is driven by climate conditions and is highly susceptible to the effects of climate change. In recent years, interest has focused on the likely response of the ecosystem to future climate change and ocean acidification. Expected long-term changes include: increased temperatures; less sea ice; and a warmer ocean. Both human-induced climate change and ocean acidification may have large impacts in the future. The effects of anthropogenic climate change are already apparent.

Examples include:

- Increased precipitation and fresh-water runoff;
- Increased release of greenhouse gases (CO_2) into the atmosphere creating a small but steady temperature increase each year — a general warming trend has been observed since the 1970s;
- Increased release of greenhouse gas emissions is also linked to ocean acidification — another emerging issue in the Barents Sea;

- A large reduction in winter ice coverage — annual sea ice extent has decreased by 50%, reaching its lowest level for the last 60 years;
- Retreating ice edges are opening new grounds for trawl fisheries and for marine transport routes. Activities in some of these newly-opened grounds may affect benthic communities that were previously protected by ice cover;
- A moderate increase in net primary production has occurred since 1997, most likely caused by a response to changes in climate that include increases in the area and duration of open water each year;
- Most commercial fish stocks have increased their prevalence northward and eastward. The distribution of Northeast Arctic cod has expanded; their occurrence has never before been recorded so far north as during 2012 and 2013.

Although climate change affects organisms inhabiting the Barents Sea ecosystem in direct and profound ways, the mechanism through which this occurs are not well understood. Thus, it remains difficult to predict what effects climate change will have upon life in the Barents Sea. Perhaps the effects of human-induced climate change and ocean acidification in combination with the potential effects of overfishing and escalating oil and gas activities are the greatest threats to sustainable productivity.

Key findings

- Air temperature over the Barents Sea remained high in 2013. The average temperature was 5.0 C°, which was above the average temperature for the period 1985-2013. During 2013, the number of days with winds exceeding 15 meters per second (m/s) was more than usual. In the Eastern Barents Sea it was the highest since 1981.
- During 2012, the average temperature of the sea in the Kola section (Russian part of the Barents Sea) the highest observed since 1900. It remained higher than normal in 2013, with increasing positive deviation to the east in the sea area. The surface water was unusually warm due to the stronger than usual seasonal warming.
- There has been a general downward trend in sea ice in the Barents Sea in the last four ten-year periods, especially in the winter. In the summer of 2013, there was no ice in the Barents Sea.

- Water masses near the surface were well mixed in the winter of 2013, with high abundance of nutrients and low biomass of phytoplankton. In the summer of 2013 phytoplankton biomass was at or close to the maximum, and has been high in the period 2008-2013.
- The total biomass of demersal fish is the highest on record. The 2013 year class of Northeast Arctic cod was large, and the spawning stock size was record high.
- The 2013 year class for polar cod was small, and natural mortality has increased, possibly due to increased predation by Northeast Arctic cod.
- The shrimp population in the Barents Sea and the waters off Spitsbergen has generally increased since the 1990s, and its distribution has moved to the northwest in the last 10 years.
- During the period 1998-2012, changes were observed in the occurrence of new fish species in the Barents Sea. The density of the cold-water fish species decreased between 2000 and 2010, but has increased slightly during the last five years. At the same time, more southern warm-adapted fish species are observed in the Barents Sea more frequently.
- During 2013, thirty-two (32) different species of sea birds were observed in the Barents Sea, with a general decrease in the number of individuals, especially in the southern areas. The largest populations were found north of the polar front; including; thick-billed murre; northern fulmar; black-legged kittiwake; and little auk. During 2013, the distributions of these species remained unchanged.
- During 2013, 12 species of marine mammals were identified in the Barents Sea. The most commonly observed species was the Barents Sea white-beaked dolphin. Most of the Barents Sea whale species are now on the IUCN’s Red List. Decreasing sea ice coverage is causing problems for several species of marine mammal, including ringed seals, hooded seal, Greenland's seal and polar bear.
- Increased human activity and new shipping routes in the Far North raise concerns about the introduction of new species in the Barents Sea. North of the Arctic Circle, six non-indigenous species are now recognized as reproducing. Of these king crab and snow crab have significant negative effects on the ecosystem.

At present, the Barents Sea remains a relatively pristine area of the Arctic with low pollution levels compared to marine areas in many industrialized parts of the world, although a wide variety of man-made chemicals are found in most components of the marine environment.

The main sources of contaminants in the Barents Sea are outside the region (introduced through long-range transport), accidental releases from local activities, and ship fuel emissions. Historically, the ecosystem has been strongly influenced by fishing and the hunting of marine mammals. Other more recent human activities include: transportation of goods; tourism; aquaculture; bio-prospecting, and industries linked to oil and gas extraction. These human pressures combine with climate variability to determine the environmental status of the Barents Sea ecosystem.

The issue of existing and potential radioactive contamination in the marine environment has received considerable attention in Norway. The Norwegian Marine Monitoring Programme (RAME) monitors radioactivity in both coastal areas and the open sea. RAME also monitors discharges from Norwegian sources, and collects discharge data for the long-range transport of radionuclides from various sources.

In the Barents Sea, overall activity concentrations of common radionuclides (such as 99Tc, 90Sr, 137Cs, 239+240Pu, 241Am, and 226 Ra) are similar to or slightly lower than concentrations observed in recent years and indicate a general trend of decrease for all the radionuclides. This can be explained by reduced discharge levels and processes such as radioactive decay, sedimentation, and dilution (NRPA, 2015).

Substantial oil and gas reserves have been discovered in the Barents Sea. Petroleum exploration is ongoing; extraction facilities are in operation in both Russian (oil) and Norwegian (gas) waters; and increasing amounts of petroleum products are being transported. Accordingly, the challenge is to ensure that these activities can take place alongside the traditional use of the sea (fisheries) without negatively affecting the marine resource base, the environment, and consumer safety.

Future shipping activities in the Barents Sea will largely depend on the expansion rate of oil-and-gas related industries in northern areas, which will depend on both regional and global economic developments. A warming climate and subsequent increase in ice-free shipping routes through Arctic waters could also contribute to increased ship traffic. Forecasts for volumes of dangerous goods being shipped in the future are not clear. Assuming that Europe remains the primary market for Russian oil, some estimates forecast a steady increase from 15 million tonnes in 2010 to 50 million tonnes in 2025.The liquid natural gas (LNG) plant at

Melkøya (Norway) ships LNG, liquified petroleum gas (LPG) and gas condensates. Working at full capacity, Melkøya ships about 5 million tonnes of LNG, LPG, and gas condensate per year. This results in about 70 gas shipments annually from Melkøya, in addition to about 300 tankers carrying Russian export petroleum cargoes westwards along the Barents Sea coast. The risk of serious accidents with oil tankers will increase in years to come, unless measures are imposed to reduce that risk.

A management plan for the Barents Sea–Lofoten area was the first developed for a Norwegian marine area (Report No. 8 (2005–2006)). The 2006 white paper states that the plan will be updated at regular intervals. The Norwegian government considers it important to ensure that the plan be implemented and followed up systematically and flexibly based on new knowledge, changes in levels of activity, trends in environment status, and other developments. The plan has been once revised: "The updating of the management plan for the marine environment in the Barents Sea and the waters off the Lofoten Islands" (Report No. 10 (2010–2011) to the Storting). A process is underway to complete another update of the management plan in 2020 and remain in effect until 2040. The Government will ensure that all affected interest groups have an opportunity to actively participate in this process.

A strategy to develop maritime activities in the Russian Federation through 2030, approved by the Federal Government on December 8, 2010 № 2205-p, provides for the inclusion of such activities within an "integrated management of marine resources". On 29.06.2014, Russian President V.V. Putin signed a list of directives based on results of a meeting on safe development of the Arctic that took place in St. Petersburg on 05.06.2014. sec. 3 specifies the task "to develop a pilot project of the integrated management of natural resources in the Arctic seas and to implement it in the Russian part of the Barents Sea". In 2014, the Russian Ministry of natural resources and environment initiated work on research and development for the pilot project on marine spatial planning in the Russian part of the Barents Sea. The project involved Joint Stock Company (JSC) SEVMORGEO, PINRO, MMBI, AARI, VNII Ecology, and WWF-Russia; it was completed in May 2015. Documents used as a basis for the project include:

Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands (2005-2006):
https://www.regjeringen.no/globalassets/upload/md/vedlegg/stm200520060008en_pdf; and

Guidelines for Marine Spatial Planning of International Oceanographic Commission UNESCO (2009): http://unesdoc.unesco.org/images/0018/001865/186559e.pdf.

Monitoring confirms that the Barents Sea environment is generally a clean sea area, with relatively low contaminant levels, with a few exceptions. Long-term data are lacking for many chemical components, and our knowledge of bioaccumulation, bio-magnification, and metabolic degradation of pollutants through the nutrient chain is limited. Another matter of concern is the distribution and content of radioactive substances in the marine environment, which may pose major risks to the whole ecosystem. Effective management of the Barents Sea ecosystem requires extensive knowledge of the ecosystem and the influence of anthropogenic drivers. This entails considering the various commercial activities which may affect the environment, and will help to ensure sustainable use of marine resources. Continued monitoring and evaluation of essential ecosystem components will be necessary to determine the changing status of the Barents Sea ecosystem and the effectiveness of management actions — whether or not management strategies improve ecosystem services and sustainability. Two types of monitoring are particularly important to integrated ecosystem assessment (IEA); 1) Trend monitoring over time to detect change in the status of an ecosystem component, and 2) Effectiveness monitoring to evaluate whether specific management actions have had the desired effect. In collaboration, Norway and Russia have developed a plan for joint monitoring of the Barents Sea that includes 22 environmental indicators; these data will support future updates of this report and will be helpful to determine appropriate management options.

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9 References

(Listed within individual chapters)