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Joint Norwegian-Russian environmental status 2013

Report on the Barents Sea Ecosystem. Short version

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The Norwegian Polar Institute is Norway's central governmental institution for management-related research, mapping and environmental monitoring in the Arctic and the Antarctic. The Institute advises Norwegian authorities on matters concerning polar environmental management and is the official environmental management body for Norway's Antarctic territorial claims.
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Electronic version on internet portal
Our report is also published on the internet using the URL
http://www.barentsportal.com.

The web publication is identical to the printed report, but you will in addition find applications which supplement and broaden some aspects in the contents. Furthermore, you will find a Web Map Service that offers the opportunity to gain a more geographic focus on some of thematic presentations on environmental issues, e.g. layer maps on top of each other for comparison. An interesting feature is the possibility to give your comments on all text and figures. Hopefully, these comments will stimulate debate on environmental issues, conditions, and future developments in the Barents Sea – or bring up questions on topics that are difficult to understand or should be broaden more. If successful, the web publication will be the main form used to update and further develop the Joint Norwegian-Russian environmental status reports on the Barents Sea Ecosystem.

Please note: In the interest of brevity, scientific citations and references are not included in this shortened version. Similarly, most tables and figures are not included. Please consult the full report published on-line for more detailed information.

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Table of Contents

1.0 Summary and key findings

The Norwegian-Russian environmental status report on the ecosystem of the Barents Sea 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 from Russia by Sevmorgeo and from Norway by the Norwegian Polar Institute in close collaboration with the Norwegian Institute of Marine Research and the Russian institute PINRO. Expert groups started its work in March 2015, and the report is based on data obtained in 2013 and 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.

Ecosystem-based management of the Barents Sea entails considering the various commercial activities that affect the. This will ensure the sustainable use of marine resources, and preserve the ecosystem components, habitats and features for the future. Proper management of the Barents Sea ecosystem assumes extensive knowledge of the ecosystem, and knowledge of the influence of anthropogenic drivers.

Key findings

The 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.

In 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.

In 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.

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 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.

Most commercial fish stocks increased their prevalence to the north and east. The total biomass of pelagic fish stocks has been consistently high since 2008. 2013 year class was larger than the long-term average.

The 2013 year class for polar cod was small, and natural mortality has increased possibly due to increased predation by cod.

The total biomass of demersal fish is the highest ever registered. The distribution of cod is extended and has never before been recorded so far north in the Barents Sea than in 2012 and 2013. The 2013 year class of cod was large and the size of the spawning stock record high.

In the period 1998-2012 changes were observed in the occurrence of new fish species in the Barents Sea. The density of the cold water species of fish lessened in the period between 2000 and 2010, but increased slightly in the last five years. On the other hand, southern warm-loving fish species are observed in the area more often.

In 2013 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 can be found north of the polar front, and that the largest populations north of the polar front are of thick-billed murre, northern fulmar, black-legged kittiwake and little auk. In 2013 the distribution of these species remains unchanged.

In 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.

Fuel consumption per kg of fish caught by the Norwegian fishing fleet has been reduced in recent years. Fishing vessels using nets and coastal purse-seiners have the lowest fuel consumption per kg of fish caught (0.07-0 .08 ltr/kg fish), while long-liners and small coastal bottom trawlers have higher fuel consumption (from 0.17-0.34 ltr/kg fish).

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.

2.0 Introduction

This is a shortened version of the Joint Norwegian-Russian environmental status on the Barents Sea Ecosystem published on website www.barentsportal. It is written to provide an easy accessible printed summary of the main findings in the full report, and is aimed at groups such as decision makers, professionals involved in ecosystem-based management and research, and journalists.

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 the status reporting is to give information of the environmental status of the Barents Sea ecosystem, including human activities, by focus on main ecosystem components and commercial activities that affect the ecosystem. The reporting will contribute to the scientific basis for development of an ecosystem based management plan for the Russian part of the Barents Sea and contribute to further development of the ecosystem based management plan for the Norwegian part of the Barents Sea.

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 status 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 briefly 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. It should be noted that although core issues are discussed, no attempt is made to address a complete list of relevant themes. Rather, directions for future research to support ecosystem-based management in the Barents Sea are pointed out.

Human activities and subsequent anthropogenic impacts are expected to increase in the future. Accordingly, the report emphasizes the importance of monitoring basic 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). The work has been carried out through the collaboration of 13 expert groups comprised of more than 130 scientists from a total of 30 Norwegian and Russian institutions. This effort has been led by PINRO and Sevmorgeo 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.

2.0 General description of the Barents Sea ecosystem

The Barents Sea is a high-latitude large marine ecosystem bordered by Norway and Russia. It is bounded by Atlantic water to the south and west and by Arctic or mixed 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 moving from the Atlantic to the Arctic Ocean, and for cold and less saline water in route from the Arctic to the Atlantic (Figure 2.1). The Barents Sea is an important feeding area for cod, capelin, haddock, herring, sea perch, catfish, plaice, halibut, Atlantic salmon, redfish, and other key species. 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. The main sources of pollution are: industrial activities linked to marine transport; extraction of petroleum products (oil and gas); and fresh-water runoff.

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. Circulation is characterized by inflow of relatively warm Atlantic water, and coastal water from the west. This 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 lower salinity than Atlantic water; it also has a stronger seasonal temperature signal. In the northern region of the Sea, fresh and cold Arctic water 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.

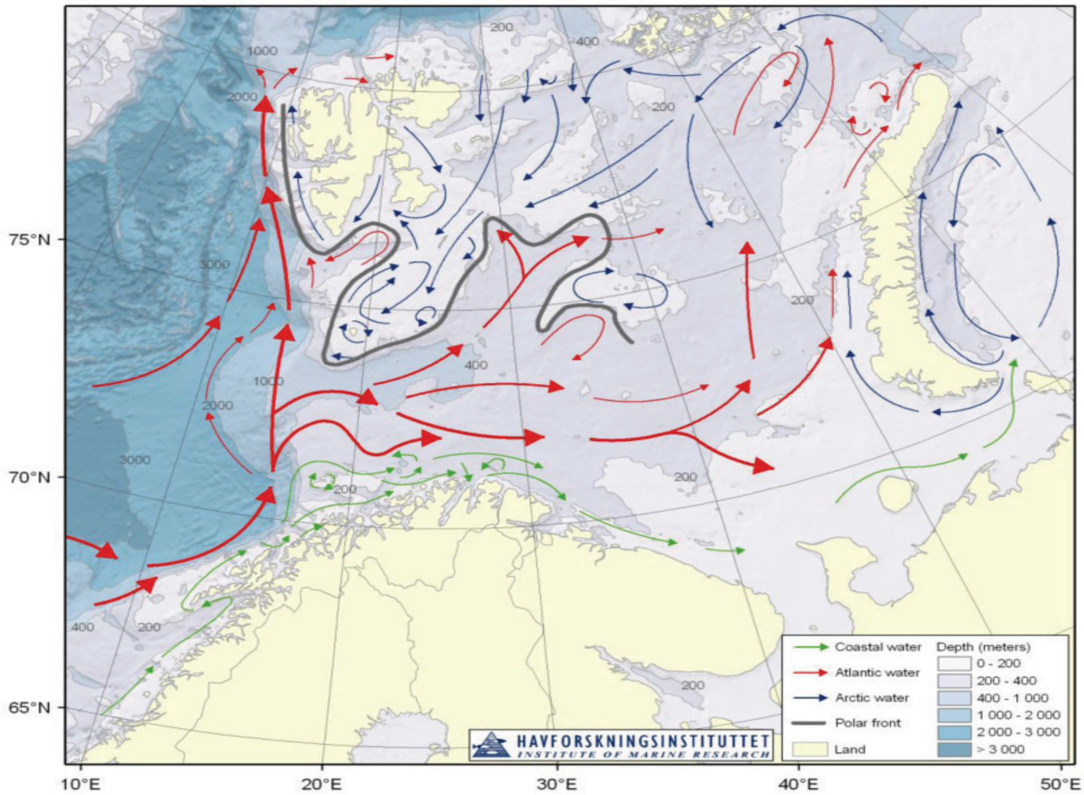

Figure 2.1. Main currents and water transport systems in the Barents Sea region.

3.0 Current status of the ecosystem

3.1 Abiotic components

Throughout 2013, air temperatures over the Barents Sea remained relatively high. Average air temperature was 5.0 ^{o}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 were mostly due to the inflow of water masses with high temperatures from the Norwegian Sea, but could 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 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.

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; in the eastern Barents Sea, it was the highest since 1981.

There has been a general decreasing trend in ice area in the Barents Sea during 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.

During fall 2011 and winter 2012, 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.

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. During 2014 the mean level of oxygen saturation again decreased (-1.5%).

3.2 Biotic components

Plankton

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 (planktonic animals in the size range 0.2-20 mm) 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 krill (euphausiids) varied between different areas of the Sea, but was generally higher than the long-term average. Arctoboreal *Thysanoessa inermis* was the dominant species.

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

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

Fishery stocks

Most fishery stocks expanded their distribution northward and eastward. The cumulative biomass of pelagic fish stocks has remained consistently high since 2008. The 2013 year class of capelin appears of average size; its biomass was approximately 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 (first year of life) 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.

The cumulative biomass of demersal fish species is the highest on record. Cod distribution has 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 maturation rate and 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.

Seabirds

During the 2013 ecosystem survey, 85,772 seabirds belonging to 32 different species were counted. 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.

Marine mammals

During the (August – October) 2013 ecosystem survey, 1,485 individual marine mammals within 12 identified species were observed. Highest species richness was in the Atlantic regions. As in previous years, the most often observed species was white-beaked dolphins (≈55%); groups of them were observed in the southern Atlantic water and up to 81°N by Franz Josef Land. 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. Six blue whales were observed along the northern shelf break and in the Hinlopen straight. 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.

Threatened and declining species

Decreasing sea-ice cover is causing problems for several species of marine mammals; including ringed seals; hooded seals; harp seals; and polar bears. The 2015 ecosystem survey should provide a basis to assess whether the polar bear stock is increasing, stable, or declining.

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).

Non-indigenous species

Increased human activity and new shipping routes in the high north raises concern for the risk of introducing new species. 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*).

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 crabs and snow crabs have become important commercial species.

3.3 Human activities and impact

3.3.1 Fisheries and other harvesting

Bottom trawl was the most widespread gear used, which had the largest effect on hard bottom habitats. 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.

Work was conducted to explore 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, contact with active fishing gears, etc.) on fish is a potential problem, but not quantified at present.

Fisheries had minimal impact on seabird mortality.

A reduction in fuel consumption per 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 bottom trawlers have higher fuel consumption (from 0.17-0.34 ltr/kg fish).

3.3.2 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. 20 December 2013 on a platform "Prirazlomnoya" a commercial production of oil has been started. The first batch of Arctic oil ARCO type (Arctic Oil) was shipped on April 18, 2014, and in September 2014 MISP "Prirazlomnaya" produced its 1st millions 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.

3.3.3 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.

3.3.4 Aquaculture

Aquaculture is a fast growing food sector in both Norwegian and Russian waters of the Barents Sea; in Norway it has grown from its pioneering days in the 1970s into a major industry. Along with expansion have come a number of operational challenges (which remain problems) related to: genetic integrity of wild stocks; parasitism; disease; and nutrient/chemical 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. 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.

3.3.5 Pollution

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.

Current status and trend for POPs

Atmospheric transport is believed to be the most important transport route for volatile and semi-volatile POPs (persistent organic pollutants) into the Arctic. 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. 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.

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.

POPs in organisms at the top of the food web are of major concern because of the accumulating properties of POPs. 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. 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.

Current status and trend for heavy metals

Monitoring heavy metals in 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. 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. No significant trends were found for mercury at any of the sites within their measurement periods.

Current status and trend for radionuclides

Current levels of contamination in sediments from technogenic radionuclides (Cs= Cesium, Sr=Strontium, Pu=Plutonium, Sb=Antimony) are very low. MMBI data for 2001-2011 show that the level of 137Cs ranges from 1 to 3 Bk/kg (becquerel per kilogram), and the level of 90Sr ranges from 0.2 to 2.0 Bk/kg.

3.4 Ecosystem effects and interactions between drivers

3.4.1 Abiotic impact

Physical conditions in the Sea are largely determined by three main water masses: Coastal Water; (North) Atlantic water; and Arctic water. These 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 result from processes taking place in the Sea itself. Year-to-year variability in sea temperatures is influenced by the relatively warm Atlantic water flowing in from southwest as well as regional heat exchange with the atmosphere. 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.

It has been demonstrate that climatic processes on the scale of the North Atlantic basin may profoundly influence the ecology of the Barents Sea. The impact of inter-annual and decadal shifts in regional climate — sea temperature in particular — on fish recruitment is also well documented. In the Sea, ‘‘warm’’ years are good 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. As 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 biological production in the north. Bottom-up processes are important as changes in climate conditions (e.g., warming and reduced sea ice) will likely influence the timing and magnitude of phytoplankton blooms and thus influence primary productivity. Despite high inter-annual variability, the ice extent in the Barents has decreased by 60% over the last 200 years.

The location of storm tracks in creating additional mixing to fuel nutrient replenishment is also an important factor influencing production. 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.

The microbial loop is an important pathway for channeling carbon through the food web. Scattered investigations in the Barents Sea indicate that small planktonic forms, including microbes, are prevalent. Investigations close to the Barents Sea entrance and in its marginal ice zone 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.

3.4.2 Biotic interactions

The composition and migratory habits of living organisms in the Barents Sea are determined by the contrast of environmental conditions between Atlantic and local water masses. 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. Of this total, benthic macrofauna (60%) and meiofauna (34%) comprise the vast majority. Most (80%) of 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 (Figure 3.1).

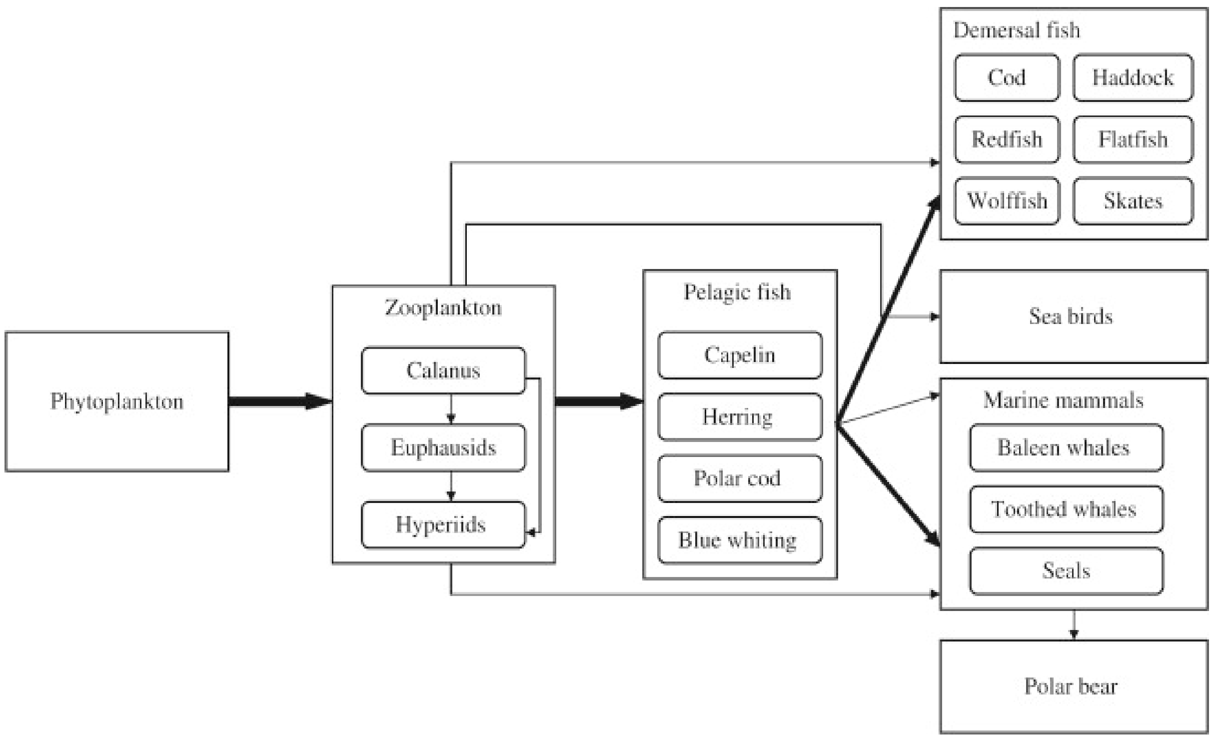

Figure 3.1. General scheme of food web in the Barents Sea ecosystem (From Yaragina and Dolgov, 2009).

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 variable climate and oceanographic conditions — directly affect overall functioning of the marine ecosystem. Zooplankton species form the trophic link between phytoplankton 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 become forage for fish, seabirds, and mammals. Blooms in Atlantic water(s) 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. 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.

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. Variability in temperature, salinity, wind conditions, and sea-ice dynamics affect primary (phytoplankton) and secondary (zooplankton) production. 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.

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. The capelin is a specialized plankton feeder, the most important planktivorous fish, and an ecological keystone species in the Barents Sea. 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; they constitute a rich food source for fish, birds, and marine mammals. Other fish at the same trophic level include juvenile herring, polar cod, blue whiting, and several other fish species during their 0-group stages.

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. Other important prey items for cod include: krill; polar cod; amphipods; shrimp; haddock; herring; blue whiting; and juvenile cod. It may also consume significant amounts of adult herring. Apart from cod, other abundant piscivorous fish stocks in the Barents include: haddock; deep-sea redfish; Greenland halibut; long rough dab; and thorny skate. In recent years, biomass estimates for other piscivorous fish species in the Barents have been low compared to that of cod and haddock (Table1). Based on available information on the diet and consumption of these species, less than half the total prey consumed is fish.

Table 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

The Barents Sea has a diverse and abundant seabird community; and one of the largest concentrations of seabirds in the world. These common and ecologically important species acquire 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. 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. The consumption of marine prey by seabirds results in a large return of nutrients to the marine ecosystem as excrement. In doing so, they play an important role in transporting organic matter and nutrients from the sea to the land. This transport has particular importance 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. 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, Novaja Zemlja, and Franz Josef Land.

Marine mammals consume production at several trophic levels in Arctic systems; because of their large body size and the abundance of some species, they are thought to have an important top-down influence on lower levels of the food web. Marine mammals which have adapted to become year-round residents in the Barents Sea include: walrus; ringed seal; bearded seal; white whale; narwhal; and bowhead whale. Harp seal is a resident in both Arctic and sub-Arctic regions of the Barents Sea. Harbour seal reside year-round in the Arctic at Svalbard; but this species, along with the grey seal, 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; fin whale; humpback whale; white-beaked dolphin; harbour porpoise; and to a lesser extent killer whale and blue whale.

4.0 Aspects of long-term future change

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.

4.1 Projections of future climate change in the Barents Sea

Projections of future changes in surface air temperature over Russia and marine areas including the Barents Sea (Figure 4.1) and precipitation (Figure 4.2) 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 4.1 d, e, f) than in summer (Figure 4.1 a, b, c). For winter, 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 Barents 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).

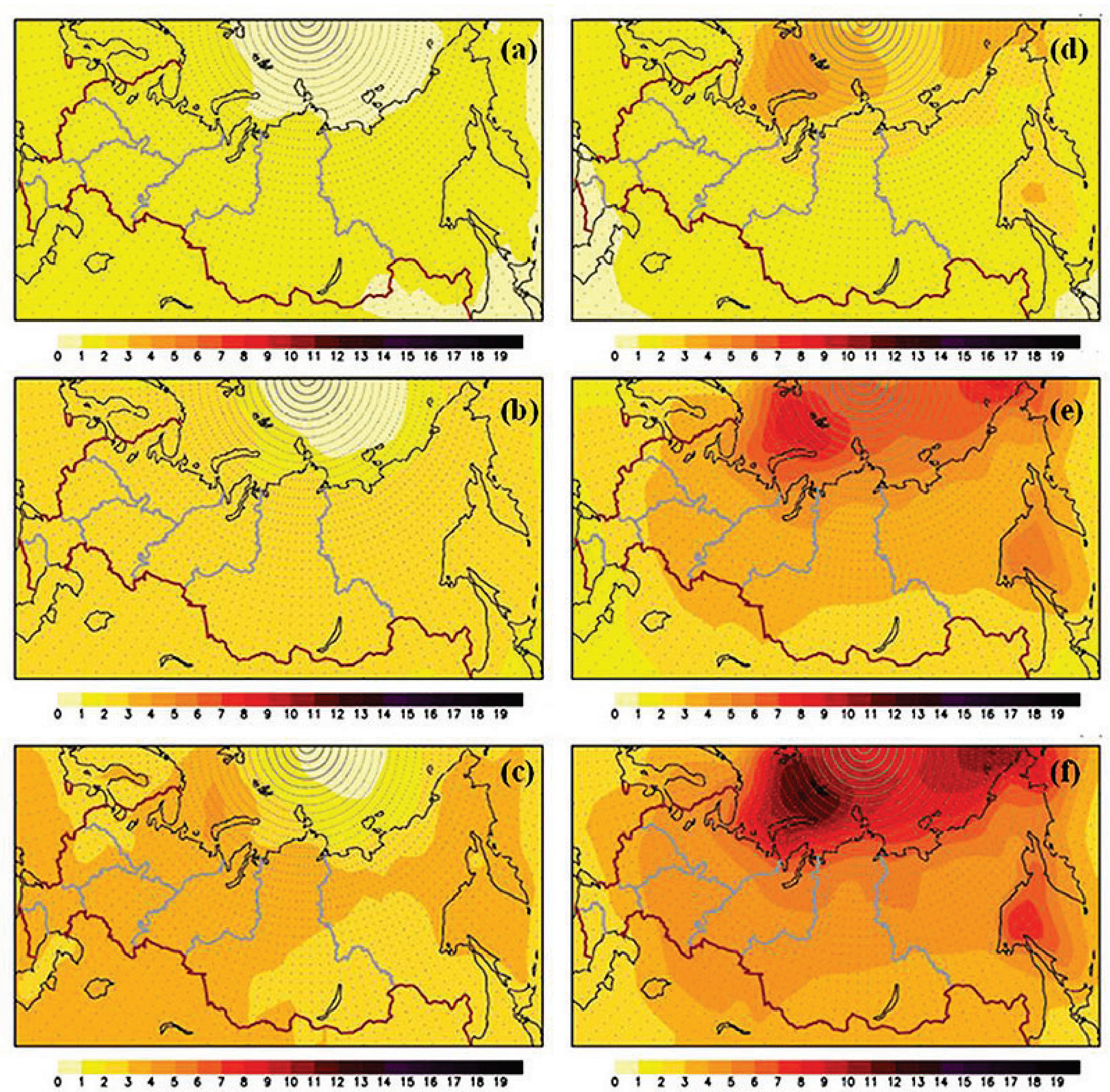

Figure 4.1.The mean anomalies of the surface air temperature for 2011–2030 (a, d), 2041–2060 (b, e) and 2080–2099 (c, f) by the end of the 21st Century for summer (a, b, c) and winter (e, f, g). The simulations were based on an ensemble of 31 CMIP5 models using RCP4.5 scenarios.

Precipitation is also projected to increase, being higher in winter (Figure 4.2 d, e, f) than in summer (Figure 4.2 a, b, c). For winter, 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, maximum anomalies are situated in the northern Barents Sea and gradually increase from 2011-2030 (5-10%) to 2080-2099 (15-20%).

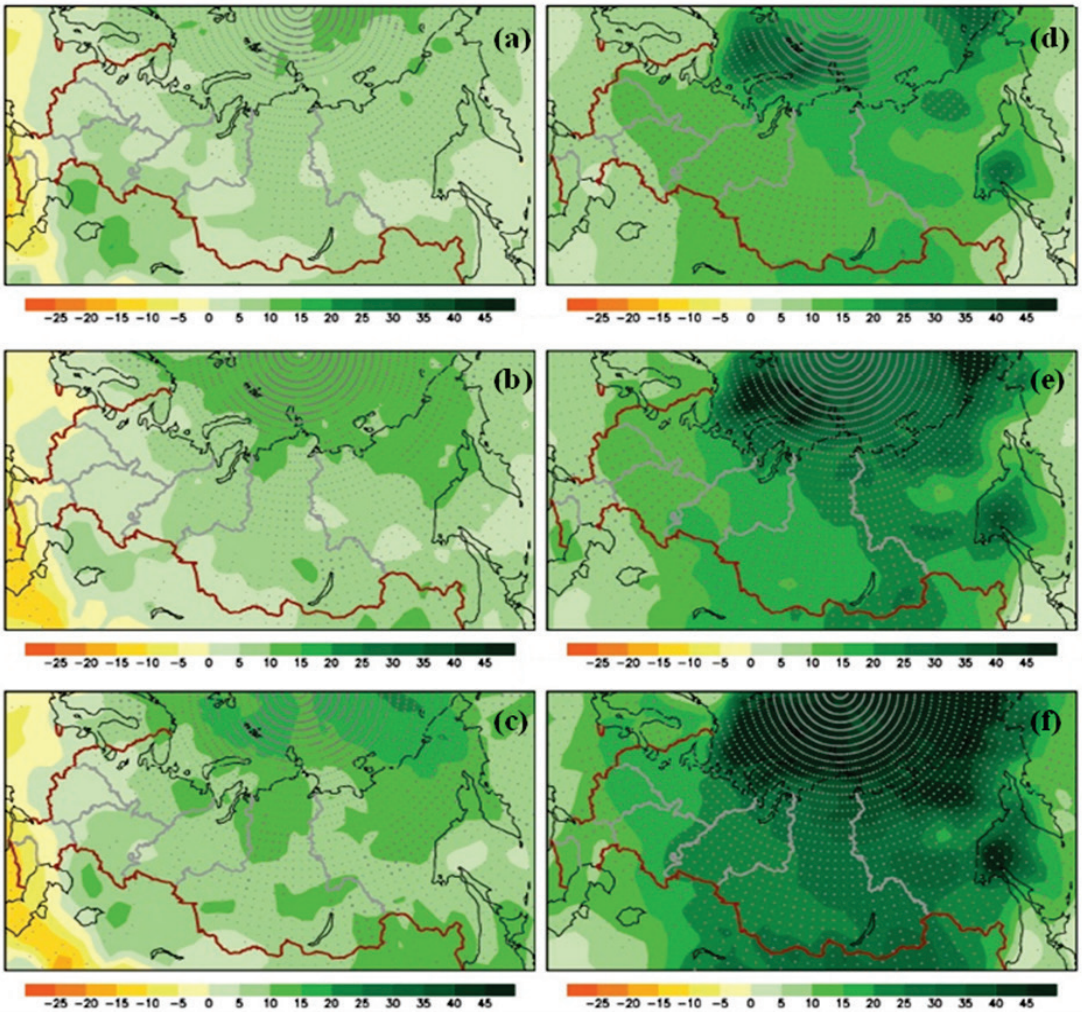

Figure 4.2. The mean precipitation anomaly (%) for 2011–2030 (a, d), 2041–2060 (b, e) and 2080–2099 (c, f) for summer (a, b, c) and winter (d, e, f) based on an ensemble of 31 CMIP5 models using RCP4.5 scenarios.

4.2 Projections of future physical oceanographic conditions in the Barents Sea

A number of early projections of oceanographic conditions for the Barents Sea have been made. It has been suggested that by 2080, surface ocean temperatures will warm by 1° to 2°C, winter sea ice will almost disappear, Atlantic water will spread farther eastward and northward, and the surface mixed-layer depth will increase due to stronger winds. It has been 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 has been projected.

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.

Changes in the position of the Polar Front that separates the cold Arctic water and warm Atlantic water have been examined. 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. A more recent study, using a Regional Circulation Model (RCM) called SINMOD, suggested that the front may move all the way to the northern shelf break adjacent to the Arctic Ocean (Figure 4.3). This would result in much warmer waters, especially in the northern Barents Sea (Figure 4.3 A, C).

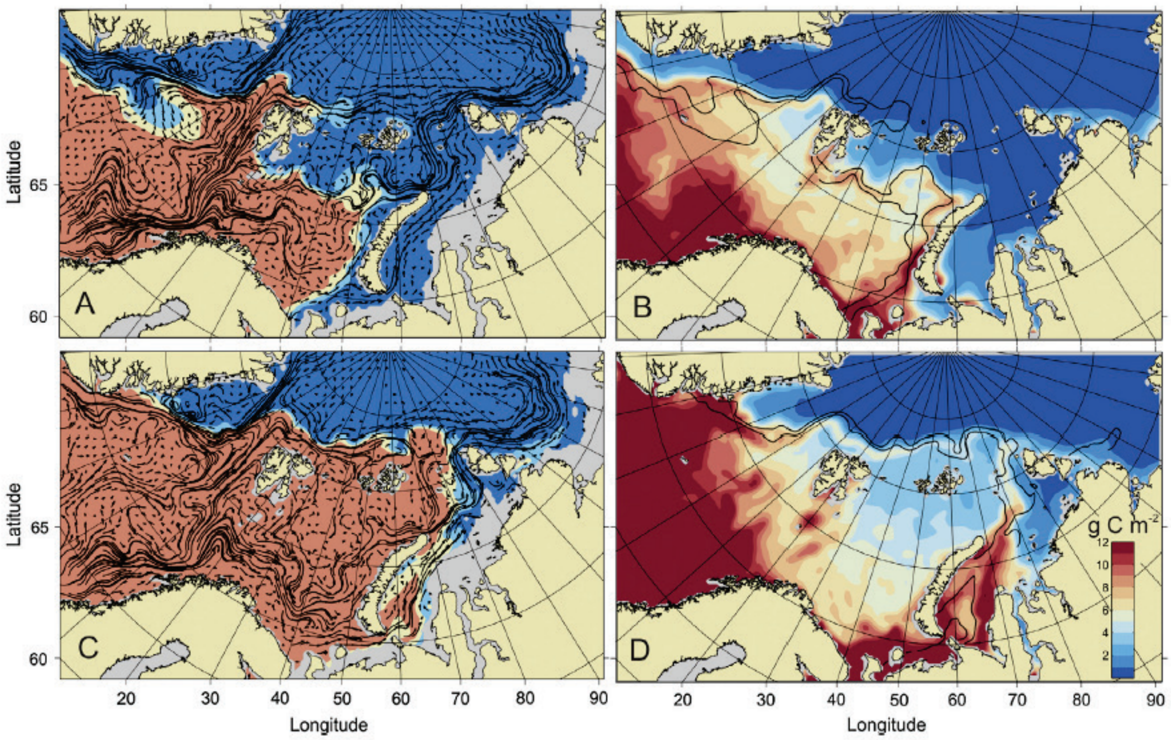

Figure 4.3. The average position of the Polar Front in April. The frontal position is indicated by the boundary between the waters less than -1°C (blue) and above +1°C (red) in panels A and C. Also shown in these panels is the average current vector at 50 m depth. The gross primary production for April 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). Two GCMs, the GISS Ocean-Atmosphere Model and the NCAR CCSM3, were used to downscale to a regional model of the Barents Sea based on ROMS (Regional Ocean Modelling System). The two global models were chosen based on their performance to recreate sea ice conditions in the Barents Sea (Overland and Wang, 2007). Downscaled 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 were less than the differences between the two GCMs. However, future scenarios from the two downscaled models were significantly different. Downscaling using the NCAR model resulted in much higher heat transport into the Barents Sea and water masses became less saline compared to using the GISS model. The authors concluded that RCM results depend largely on the GCM chosen to downscale from; hence, exactly what will happen in the Barents Sea under climate change remains somewhat uncertain. One approach to overcome 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 spread in the model results would indicate the uncertainty in the projections. Also, there is a need to couple atmosphere and ocean for the regional models, which even in the recent modelling was not attempted. In a coupled model system, changes in ocean feedback to the atmosphere are incorporated; in an uncoupled system, there is no feedback.

It is clear however that under climate change, temperatures will rise in the Barents Sea somewhere between 2°-10°C, and that sea ice will be significantly reduced and may disappear altogether. Salinities are generally expected to decline due to increasing precipitation and higher fresh-water runoff from rivers. Peak river runoff will occur earlier in the year. The Polar Front will move to the northeast 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 climate. Results from the NorESM1-M coupled climate model have been used to show that the negative trend in sea-ice coverage reflects the major trend of heat transport through the Barents Sea Opening. It was concluded that the ocean has a stronger direct impact on changing sea-ice coverage than does the atmosphere. It similarly has been concluded that loss of ice cover in the Barents Sea is driven by increased transport of heat into the region with inflowing Atlantic water. Researchers have found that correlations — between the Barents Sea ice coverage and the North Atlantic Oscillation — are highly variable yet remain relatively low over extended periods of time. Earlier findings of a strong Atlantic Multi-decadal Oscillation (AMO) like signal in Barents Sea temperatures and in Arctic sea-ice variability have been supported. The AMO has a period of 60-80 years and is believed to be linked to changes in the Meridional Overturning Circulation.

4.3 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. This ocean acidification is extremely rapid in northern sea areas compared to other global oceans. It is expected that organisms living at high latitudes will be among the first affected. If acidity increases, this will significantly reduce the ability of organisms to build calcium carbonate shells and skeletons. 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.

4.4 Effects of climate change on pollution

Climate change may have a complex set of influences on both the 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.

5.0 Issues relevant for ecosystem-based management

It must be cautioned that not only are the atmospheric and ocean climate scenarios highly uncertain, but their impacts are as well. Also, climate change is just one of the global change issues that marine environments are subjected to; other issues, such as fishing and ocean acidification, will also play a role and must be taken into account for projections of future conditions. Several projections were based on previous relationships between climate and food webs. It cannot be expected, however, that such relationships will continue without end, as many of them are time variant. With the high uncertainty and our lack of ability to forecast the future accurately, we must develop management strategies which are robust to unforeseeable changes in stock dynamics.

5.1 Future foodwebs in the Barents Sea under climate change

It is clear that the projected changes in ocean climate indicated above will have significant impacts on organisms in the Barents Sea. A full discussion on expected biological responses to the physical changes is beyond the scope of the present report. However, in the following we present some changes which may occur.

5.1.1 Plankton

In seasonally ice-covered areas where the ice will disappear or be reduced under climate change, annual primary production is projected to increase due to higher light levels and an extended growing season. Moreover, 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 climate scenario through earlier onset of density stratification of the water column.

It has been 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. Indeed, the loss of Arctic zooplankton species the northern Barents Sea has been observed during recent years in association with warm temperatures and reduced ice cover.

5.1.2 Fish

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. Model studies suggest that higher primary production tends to increase cod recruitment. However, any increase in cod recruitment and abundance will depend on the changes in secondary (zooplankton) production, in particular *C. Finmarchicus* — the primary prey for cod larvae. The expected increased abundance of *C. finmarchicus* in the Barents Sea under future climate change supports the contention that cod recruitment will likely increase. However, not all models agree. It has been predicted that cod production would decline later during the 21st century owing to a decrease in zooplankton productivity. While these possible changes for Atlantic cod under future warming are consistent with past observations, the actual response remains uncertain. Indeed, it has been noted that improved understanding of the physiological and behavioural responses of cod to changes in environmental conditions, as well as the responses of other components of the marine ecosystem, are required for future cod projections.

Investigations of other species suggest that they will be substantially impacted as well; other boreal fish species are expected to extend farther east and north. The eastward expansion of herring, blue whiting, and possibly Atlantic mackerel are expect to result in new species interactions and potentially to changes in the structure and function of the ecosystem. Capelin has been observed to have moved northward in response to the present warm temperatures and reduced ice. It has been suggested that a relatively large number of invasive species can be expected in the Sea Barents, as well as local extinctions and species turnovers related to distribution shifts. Polar cod may remain in the Barents Sea, but would lose the ice-associated part of its life cycle, and its summer distribution area 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. Salmon abundance likely will increase in Russian waters as previously observed under warm conditions, and also extend its range to northern Svalbard. Recent increase in jellyfish abundance in the Barents Sea has been noted in association with warmer waters, and more jellyfish are likely to appear as temperatures continue to increase.

5.1.3 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. It has been 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. 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 body weight during 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. 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 100 km from their breeding sites but this range may be extended.

5.2 Effects of overfishing

Observed variations, in both fished species and the ecosystem as a whole, are also the effect of other pressures such as predation and climate. 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.

Nevertheless, fishing is believed to have the largest human impact on the fish stocks in the Barents Sea, and thereby on the structure and functioning of the whole ecosystem. Fisheries for pelagic stocks also strongly impact the ecosystem by intensifying these inherent fluctuations; thereby, increasing instability in the entire ecosystem. Overfishing clearly contributed to complete collapse of the herring stock at the end of the 1960s, and may also have contributed to the capelin stock collapse in the mid-1980s.

The reduced herring stock in 1983 limited its potential to rebuild following good recruitment conditions in 1983-85. Therefore, subsequent herring year classes were 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 higher levels of the food web, e.g. dying seals and birds, and economic ruin for many fishermen.

5.3 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. 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. 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. 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.

5.4 Habitat destruction (due to fishing)

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. Some 109 species of sponge are found along the coast of Norway, 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.

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. 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. 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. Side-scan and video recordings of sandy/gravel bottom in the Barents Sea have shown physical disturbance from trawling, with highly visible furrows (10cm deep and 20 cm wide) and berms (10cm high) caused by trawl doors and smaller depressions created by rockhopper gear.

5.5 Russian Integrated management plan

Strategy for the Development of maritime activities of the Russian Federation for the period up to 2030 was approved by the Federal Government on December 8, 2010 № 2205-р. The strategy includes topics concerning development of “*integrated management of marine resources”* and “*utilization and development of marine spatial planning tools”*. On 29.06.2014, Russian President V.V. Putin signed a list of directives for the Government of the Russian Federation based on the results of the meeting on *Safe Development of the Arctic* that took place in St. Petersburg on 05.06.2014. Section 3 in the directive specifies that the Government shall *"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, Russian Ministry of Natural Resources and Environment initiated a project to compile available scientific knowledge from the Barents Sea as a scientific basis for development of a pilot project on marine spatial planning in the Russian part of the Barents Sea. The compiling was completed in May 2015 by a consortium consisting of JSC "Sevmorgeo", PINRO, MMBI, AARI, VNII Ecology and WWF-Russia. Two main documents were used as a basis for the project: Norwegian integrated marine management plan for the *Barents Sea and the Sea Areas off the Lofoten Islands (2006)*[1] and Guidelines for Marine Spatial Planning of International Oceanographic Commission UNESCO (2009)[2].

Current status for development of a marine spatial planning in the Russian part of the Barents Sea is that the work continue after instructions established in the Action plan for 2015-2018 for the execution of the mission from the Russian president by 29.06.2014 no. 1530, Section 3 specifies " to prepare a pilot proposal for comprehensive natural resource management in the Arctic sea and the realization of this in the Russian part of the Barents Sea".

6 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).

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

[1] The Royal Norwegian Ministry of the Environment. Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands. Report No. 8 to the Storting (2005–2006).

[2] Ehler, Charles, and Fanny Douvere. Marine Spatial Planning: a step-by-step approach toward ecosystem-based management.Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides no. 53,ICAM Dossier No. 6. Paris: UNESCO. 2009 (english).

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.

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.[3] 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) Increased effort on IEA-relevant monitoring
2) Strengthened coordination of joint Norwegian-Russian monitoring of the Barents Sea
3) Further development of the framework for joint reporting status on the status of the Barents Sea ecosystem.

[3] Korneev, O., O. Titov, G van der Meeren, P. Arneberg, J. Tchernova, N.M, Jørgensen. Final report 2012-2015, Joint Russian-Norwegian Monitoring Project – Ocean 3. Norwegian Polar Institute, Brief Report Series no. 30, 2015.

All material in this short version has been drawn from the full version of the status report which is published in **www.barentsportal.com**. Below are listed the more than 130 experts from 9 Russian and 21 Norwegian institutions who have contributed to the full version including experts from the report published in 2009[4].

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[4] Stiansen, J.E, Korneev, O., Titov, O., Arneberg, P. (Eds.). Filin, A., Hansen, J.R., Høines, Å., Marasaev, S. (Co-eds) 2009. Joint Norwegian-Russian environmental status 2008. Report on the Barents Sea ecosystem. Part II, Complete report. IMR/PINRO Joint Report Series, 2009 (3), 375 pp. ISSN 1502-8828.

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034 KORTRAPPORT / BRIEF REPORT
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