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Part II - Complete report

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The web publication is identical to the printed report, but you will in addition find ads that supplements and broadens some aspects in the contents. Furthermore, you will find a Web Map Service which gives you the opportunity to have a more geographic focus on some of the thematic presentation of environmental issues, and e.g. add other maps on top for comparison. An interesting feature is the possibility to give your comments on all text and figures. Hopefully, these comments will stimulate to debates on environmental issues, condition and future development in the Barents Sea – or bring up questions on topics that are difficult to conceive or should be broaden more. If prosperous, the web publication will be the main form for updating and developing of the Joint Norwegian-Russian environmental status reports on the Barents Sea Ecosystem.

The report may alternatively be downloaded at
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Joint Norwegian-Russian environmental status 2008 Report on the Barents Sea Ecosystem

Part II – Complete report

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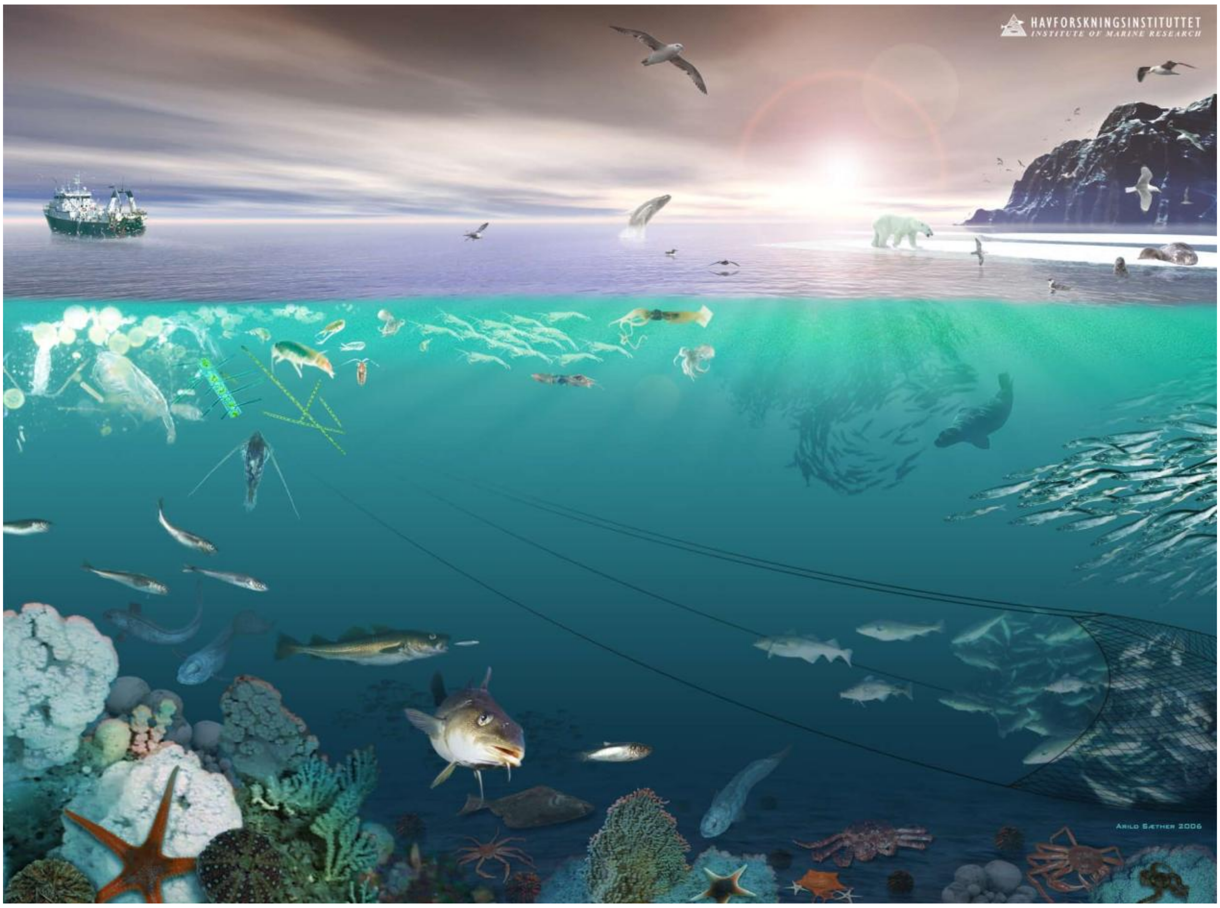

Illustration of the rich marine life and interactions in the Barents Sea

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Table of content

1 Introduction

P. Arneberg (NPI), O. Korneev (SMG), J.E. Stiansen (IMR) and O. Titov (PINRO)

Background

This report is a co-operation project between the Joint Russian - Norwegian Commission on Environmental Cooperation and the Joint Russian-Norwegian Fisheries Commission. The initiative to the report was taken by the environmental commission and was later acknowledged by the fisheries commission. Formally, it is the realisation of Project no. 1 of the Work Program for 2009-2010 for the Russian-Norwegian Environmental Cooperation, as approved by 14th meeting of the environmental commission. The work has been carried out under the umbrella of the Marine Working Group of the environmental commission and has build on the experiences from the series of previous joint PINRO/IMR reports on the status of the Barents Sea ecosystem (Stiansen et al 2006, 2007, 2008). More than 100 experts from a total of 9 Russian and 20 Norwegian institutions have participated in the preparation of the report, and the work has been organised in 13 expert groups. The work has been led by Sevmorgeo and PINRO on Russian side and on Norwegian side by the Institute of Marine Research and the Norwegian Polar Institute. The expert groups started their work in November 2008, and the report thus builds on data collected in 2008 and earlier.

The main objective of the report is to give a comprehensive description of the Barents Sea ecosystem, including human activities and impact in the area, using relevant scientific and monitoring knowledge from Norwegian, Russian and other sources. The report will contribute to the knowledge 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. The Barents Sea has internationally been identified as a single large marine ecosystem (LME). The scientific basis from this project will therefore also contribute to the whole Barents Sea ecosystem being a consideration when the two countries further develop ecosystem based management in their respective parts of the sea area.

Knowledge basis for ecosystem based management

A number of features characterise ecosystem based management. An overarching issue is that different types of human impact should not be considered isolated from each other, as is often done in the traditional sector based management that typically precedes ecosystem based management. Rather, what needs to be focused is the combined impact of different activities on the ecosystem.

This largely determines the framework in which knowledge for ecosystem based management should be assembled and developed. It implies that in addition to broad knowledge about the different elements of the ecosystem, knowledge of impact from all major anthropogenic drivers is required. This should finally be used to assess what the combined impact of the various drivers are on the different components of the ecosystem.

It should be noted that this also implies that knowledge about the overall dynamics of the ecosystem is needed, because anthropogenic impact on one set of components in the ecosystem may spread to other components through the pathways on which species naturally interact with each other. In addition, knowledge of influence of the physical environment is needed, because this can affect how the ecosystem responds to anthropogenic impact.

Structure of the report
In this report, a general description of the components of the ecosystem is given in chapter 2. This includes descriptions of the physical environment and the main biological components. In addition, general descriptions of the different human activities in the Barents Sea are also given here. Chapter 2 ends with a discussion of how the ecosystem is affected by natural variation in the physical environment, the natural dynamics of species interaction and how different anthropogenic activities generally affect the ecosystem.

In chapter 3, the monitoring that is used to collect the data on the state of the ecosystem and the human activities are described.

In chapter 4 the most recent of these data, much of it collected in 2008, are used to describe the current status of the ecosystem. Current status for the different components of the ecosystem and human activities and impact are first described in separate subchapters. These subchapters and the general description of the dynamics of the ecosystem given in chapter 2 are then used as input to discuss the overall current dynamics of the ecosystem. This discussion is given in subchapter 4.5. Here, conclusions are drawn about the impact of major anthropogenic drivers on the status of the ecosystem. This is done partly by comparing and drawing on knowledge about human impact on other marine ecosystems in the North Atlantic and the North Sea.

Possible long term changes caused both by some of the main drivers are discussed in subchapter 4.6. Effective management requires adaptive management strategies that reflect changing circumstances. This is especially important in view of the impact of anticipated climate change and ocean acidification on marine ecosystems.

It should be emphasised that although overall analyses of the combined impact of all human drivers on the ecosystem is ultimately needed when developing ecosystem based management, such analyses are beyond the scope of this report. Chapter 4.5 nevertheless go some of the way towards this. Most importantly, the general description and analyses of impact from different human activities throughout the report provide additional pieces of information to be used in such overall assessments.

In chapter 5, it is discussed how the contents of the previous chapters may be used to further develop ecosystem based management. The chapter takes the form of highlighting and discussing important issues that are relevant for development of ecosystem based management. This also includes considerations about the importance of considering the combined impact of different anthropogenic drivers. It should be emphasised that although core issues are discussed, no attempt is made to give a complete list of themes relevant for ecosystem based management, but rather to highlight some of the important lines of work beyond this report.

Summary and major conclusions are given in the chapter 6.

2 General background description of the ecosystem

2.1 Overview of the ecosystem

Å. Høines (IMR), A. Filin (PINRO) and J.E. Stiansen (IMR)

The Barents Sea is a sub-Arctic ecosystem located between 70 and 80ºN. It connects with the Norwegian Sea to the west and the Arctic Ocean to the north. The average depth is 230 m and the maximum depth is approximately 500 m at the western entrance. The general pattern of circulation (Figure 2.1.1) is strongly influenced by this topography, and is characterised by inflow of relatively warm Atlantic water, and coastal water from the west. This current 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. The Coastal Water has more fresh-water runoff and a lower salinity than the Atlantic water; it also has a stronger seasonal temperature signal. In the northern region of the Barents Sea, fresh and cold Arctic waters flow from northeast to southwest. Atlantic and Arctic water masses are separated by the Polar Front, which is characterised by strong gradients in both temperature and salinity. There is large inter-annual variability in ocean climate related to variable strength of the Atlantic water inflow, and exchange of cold Arctic water. Thus, seasonal variations in hydrographic conditions can be quite large.

In the biogeochemical cycles of the ocean, a multitude of processes are catalyzed by *Bacteria* and *Archaea*, and the functioning of these cycles in the Barents sea do not differ qualitatively from those at lower latitudes. Both bacteria and viruses show highly variable abundance in the Barents Sea, and in general, the dynamics of these groups in this area do not differ from other parts of the ocean. The situation in the ice-covered areas in the north remains to be investigated.

The Barents Sea is a spring bloom system. During winter, primary production is close to zero. Timing of the phytoplankton bloom varies throughout the Barents Sea and there may also be a high inter-annual variability. The spring bloom starts in the south-western areas and spreads north and east with the retracting ice. In early spring, the water is mixed from surface to bottom. Despite adequate nutrient and light conditions for production, the main bloom does not occur until the water becomes stratified.

Stratification of water masses in different areas of the Barents Sea 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). As in other areas, diatoms are also the dominant phytoplankton groups in the Barents Sea (Rey, 1993). Diatoms particularly dominate the first part of the spring bloom, and the concentration of diatoms can reach up to several million cells per litre. They require silicate for growing, and when this is consumed, other phytoplankton groups, such as flagellates, take over. An important flagellate species in the Barents Sea is *Phaeocystis pouchetii* but other species may, however, predominate the spring bloom in different years.

In the Barents Sea ecosystem, zooplankton forms a link between phytoplankton (primary producers) and fish, mammals and other organisms at higher trophic levels. Zooplankton biomass in the Barents Sea can vary significantly between years and crustaceans are important. The calanoid copepods of the genus *Calanus* play a key role in this ecosystem. *Calanus finmarchicus*, is most abundant in Atlantic waters and *C. glacialis* is most abundant in Arctic waters. Both form the largest component of zooplankton biomass.

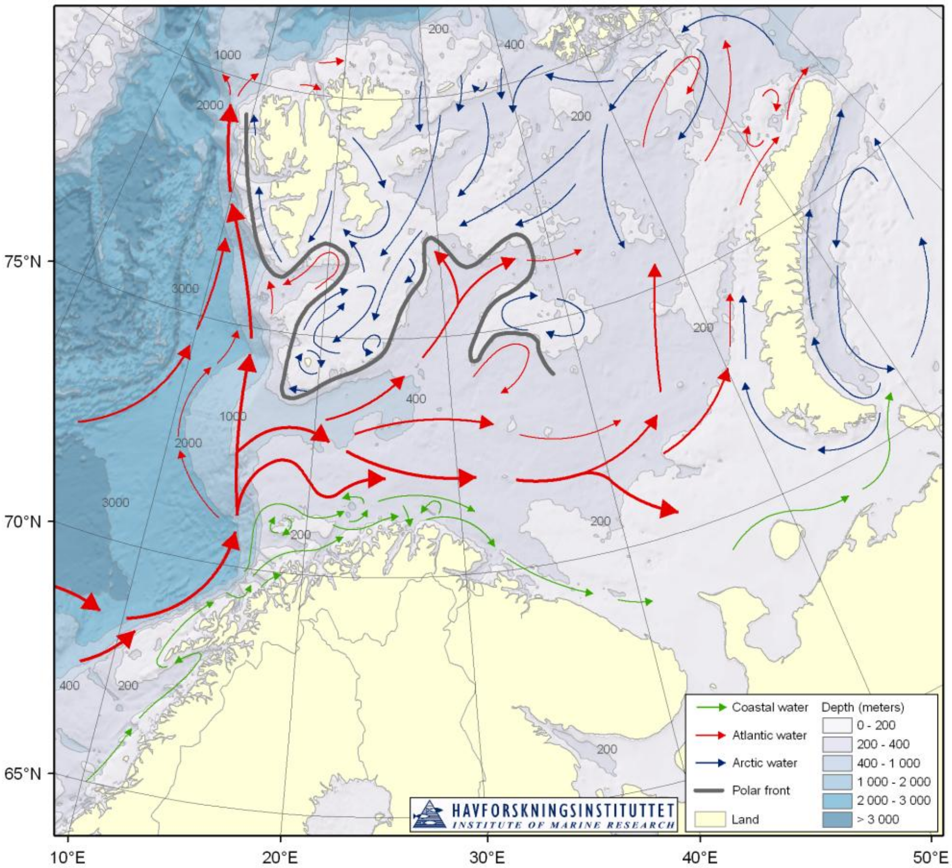

Figure 2.1.1. Main features of circulation and bathymetry in the Barents Sea.

Calanoid copepods are largely herbivorous, and feed particularly on diatoms (Mauchline, 1998). Krill (euphausiids), another group of crustaceans, also play a significant role in the Barents Sea ecosystem as food for fish, seabirds, and marine mammals. Krill species are believed to be omnivorous: filter-feeding on phytoplankton during the spring bloom; while feeding on small zooplankton during other times of the year (Melle et al., 2004). Four dominant species that occupy different niches in the community of Barents Sea euphausiids are: *Meganyctiphanes norvegica* (neritic shelf boreal); *Thysanoessa longicaudata* (oceanic arcto-boreal); *T. inermis* (neritic shelf arcto-boreal); and *T. raschii* (neritic coastal arcto-boreal) (Drobysheva, 1994). The two latter species comprise 80-98% of total euphausiid abundance, but species composition may vary between years relative to climate (Drobysheva, 1994). After periods with cold climate, observed abundance of *T. raschii* increased while abundance of *T. inermis* decreased (Drobysheva, 1967). Advection from the Norwegian Sea is influenced by the intensity of Atlantic water inflow, which also influences the composition of species (Drobysheva, 1967; Drobysheva et al., 2003).

Three amphipod species were found abundant in the Barents Sea; *Themisto abyssorum* and *T. libellula* in the western and central Barents Sea, and *T. compressa* is found, albeit less abundant, in central and northern regions. *T. abyssorum* is most abundant in sub-Arctic waters. In contrast, the largest of the *Themisto* species, *T. libellula*, is largely restricted to combined Atlantic and Arctic water masses. High abundance of *T. libellula* was observed adjacent to the Polar Front. Amphipods feed on small zooplankton and copepods form an important component of their diet (Melle et al., 2004).

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*. Both comb-jellies (*Ctenophora*) and "true" jellyfish are predators, and they compete with plankton-eating fish, because copepods often are significant prey items. The sea floor is inhabited by a wide range of organisms. Some are buried in sediment, others are attached to a substrate, some are slow and sluggish, others roving and rapid. Many feed by actively or passively, sieving food particles or small organisms from the water. Others eat the bottom sediments (detritus feeders), eat carrion (scavengers) or hunt other animals (carnivores). The high diversity among bottom animals is presumed to be due to the abundance of micro-habitats that organisms can adapt. In shallow waters, kelp forests are feeding and nursery habitats for several many species of fish, birds, and mammals. Below the sublittoral zone, sea anemones, sponges, hydrozoans, tunicates, echinoderms, crustaceans, molluscs and many other animal groups abound on hard substrates. These large conspicuous animals are not abundant on sand or muddy bottoms, and in fact some of these habitats may at first look rather lifeless. However, most of the benthic animals in these habitats live buried in the sediments. *Polychaete* worms, crustaceans and bivalves are found in the sediments well as a myriad of other taxa. Some muddy areas might have dense aggregations of brittle stars, sea stars or bivalves.

More than 3050 species of benthic invertebrates inhabit the Barents Sea (Sirenko, 2001). The benthic ecosystems in the Barents Sea have considerable value, both in direct economic terms, and in their ecosystem functions. Scallops, shrimp, king crab, and snow crab are benthic residents which are harvested in the region. Many species of benthos are also interesting for bio-prospecting or as a future food resource, such as sea cucumber, snails and bivalves. Several of them are crucial to the ecosystem. Important fish species such as haddock, catfish and most flatfishes primarily feed on benthos. Many benthic animals, primarily bivalves, filter particles from the ocean and effectively clean it up. Others scavenge on dead organisms, returning valuable nutrients to the water column. Detritius feeders and other active diggers regularly move the bottom sediments around and therefore increase sediment oxygen content and overall productivity – much like earthworms on land.

More than 200 fish species are registered in trawl catches during surveys of the Barents Sea, and nearly 100 of them occur regularly. Even so, the Barents Sea is a relatively simple ecosystem, with few fish species of potentially high abundance. Different species of fish are not evenly distributed throughout the Barents Sea. Rather, they exhibit highest abundance in areas with suitable environmental conditions. Commercially important fish species include Northeast Arctic cod, Northeast Arctic haddock, Barents Sea capelin, polar cod and immature Norwegian spring-spawning herring. In years, increased numbers of young blue whiting have migrated into the Barents Sea. Species distribution largely depends on positioning of the Polar Front. Variation in recruitment of species, including cod and herring, has been linked to changes in influx of Atlantic waters.

Cod, capelin, and herring are key species in the Barents Sea trophic system. Cod prey on capelin, herring, and smaller cod; while herring prey on capelin larvae. Cod is the most important predator fish species in the Barents Sea, and feeds on a wide range of prey, including larger zooplankton, most available fish species and shrimp. Capelin feed on zooplankton produced near the ice edge. Farther south, capelin is the most important prey species in the Barents Sea as it transports biomass from northern to southern regions (von Quillfeldt and Dommasnes, 2005). Herring, another prey species for cod, has similar abundance, and high energy content. Herring is also a major predator on zooplankton.

Marine mammals, as top predators, are keystone species significant components of the Barents Sea ecosystem. About 25 species of marine mammals regularly occur in the Barents Sea, including: 7 pinnipeds (seals and walruses); 12 large cetaceans (large whales); 5 small cetaceans (porpoises and dolphins); and the polar bear (*Ursus maritimus*). Some of these species are not full-time residents in the Barents Sea, and use temperate areas for mating, calving, and feeding (e.g. minke whale *Balaenoptera acutorostrata*). Others reside in the Barents Sea all year round (e.g. white-beaked dolphin *Lagenorhynchus albirostris*, and harbour porpoise *Phocoena phocoena*). Some marine mammals are naturally rare, such as the beluga whale *Delphinapterus leucas.* Others are rare due to historic high exploitation, such as bowhead whale *Balaena mysticetus* and blue whale *Balaenoptera musculus*.

Marine mammals may consume up to 1.5 times the amount of fish caught in fisheries. Minke whales and harp seals may each year consume 1.8 million and 3-5 million tons of prey of crustaceans, capelin, herring, polar cod, and gadoid fish respectively (Folkow et al., 2000; Nilssen et al., 2000). Functional relationships between marine mammals and their prey seem closely related to fluctuations in marine ecosystems. Both minke whales and harp seals are thought to switch between krill, capelin and herring depending on availability of the different prey species (Lindstrøm et al., 1998; Haug et al., 1995; Nilssen et al., 2000).

Fish and mammals have seasonal feeding migrations so that the stocks in the area will have their most northern and eastern distribution in August-September and be concentrated in the southern and south-western areas in February-March. The Barents Sea has one of the largest concentrations of seabirds in the world (Norderhaug et al., 1977; Anker-Nilssen et al., 2000); its 20 million seabirds harvest annually approximately 1.2 million tonnes of biomass from the area (Barrett et al., 2002). Nearly 40 species are thought to breed regularly in northern regions of the Norwegian Sea and the Barents Sea. Abundant species belong to the auk and gull families. 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.

There are 10 types of parasites found in the fish of the Barents Sea, but it is hard to determine which groups of parasitic organisms that play an important role in the population dynamics of their hosts. The Barents Sea parasites considered to be most damaging to the human health are larvae stages of *Cestoda* (*Diphyllobothrium* and *Pyramicocephalus* genera), *Nematoda* (*Anisakis* and *Pseudoterranova* genera) and *Palaeacanthocephala* (*Corynosoma* genera). 82 species of helminthes are recorded from 18 bird species. The Barents Sea birds' helminthofauna mostly consists of the species with the life cycle dependent on coastal ecosystems. Invertebrates and fish from the littoral and upper sub littoral complex serve as their intermediate hosts.

The Barents Sea includes species that either have very small populations or species that have recently undergone considerable population decline (or are expected to do so in the close future). The assessments are done by use of the IUCN criteria (IUCN, 2001; 2003), but the Global, the Russian and the Norwegian lists available can not be directly compared. All these lists are closely related and have high relevance for the conservation of biodiversity, and the list from the Barents Sea include a total of 56 species comprising of 28 fish species, 9 bird species, and 18 mammal species.

Invasions of alien species – spread of the representatives of various groups of living organisms beyond their primary habitats – are global in nature. Their introduction and further spread often leads to the undesirable environmental, economic and social consequences. Different modes of biological invasions can be natural movement associated with the population dynamics and climatic changes, intentional introduction and reintroduction, and accidental introduction with the ballast waters and along with the intentionally introduced species, etc. The best known examples of introduced species in the Barents Sea are red king crab *(Paralithodes camtschaticus)* and snow crab *(Chionoecetes opilio)*.

The Barents Sea is strongly influenced by human activity; historically involving the fishing and hunting of marine mammals. More recently, human activities also involve transportation of goods, oil and gas, tourism and aquaculture. In the last years interest has increases on the evaluation of the most likely response of the Barents Sea ecosystem to the future climate changes due to anthropogenic effect on climate warming.

Fishing is the largest human impact to the fish stocks in the Barents Sea, and thereby the functioning of the whole ecosystem. However, the observed variation in both fish species and ecosystem is also impacted by other effects such as climate and predation. The most widespread gear used in the central Barents Sea is bottom trawl, but also long line and gillnets are used in the demersal fisheries. The pelagic fisheries use purse seine and pelagic trawl.

The Barents Sea remains relatively clean, however, when 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. Results of recent studies indicate low level of contaminants in the Barents Sea marine environment and confirm results of earlier studies on bottom sediments in the same areas. In the near-term, observed levels of contaminants in the marine environment should not have significant impact on commercially important stocks and on the Barents ecosystem as a whole.

Traditionally, fishing having been the most important and far-reaching human activity in the ecosystem has been given most of the attention with analyses of impacts and risks. This need has increased in importance as oil- and gas industries have begun to develop new off-shore fields in the Barents Sea, and ship transport of oil and gas from the region has increased exponentially over the last 5 years.

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), but this may increase in the future with development of new oil- and gas fields. In Russia there are plans for the development of Stochkman, a large gas-field west of Novaya Zemlja. 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.

Transport of oil and other petroleum products from ports and terminals in NW-Russia have been increasing 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.

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 characterised 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.

Ocean acidification is greater and happening faster than any previous acidification process experienced in millions of years. The absorption of CO_2 generally goes faster in colder waters and thus will rapidly affect the Barents Sea.

2.2 Geographical description

D. Howell (IMR), A. Filin (PINRO) and J.E. Stiansen (IMR)

The Barents Sea is on the continental shelf surrounding the Arctic Ocean. It connects with the Norwegian Sea to the west and the Arctic Ocean to the north. 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 (see Figure 2.1.1). It covers an area of approximately 1.4 million km^2, has an average depth of 230 m, and a maximum depth of about 500m at the western end of Bear Island Trough (Figure 2.1.1). Its topography is characterized by troughs and basins (300 m – 500m deep), separated by shallow bank areas, with depths ranging from 100-200 m. 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 troughs allow the influx of Atlantic waters to the central Barents Sea.

The Barents Sea area has undergone two major orogenic (mountain building) geologic episodes. The first was during the Caledonian orogeny (around 400 million years ago), the second around 240 million years ago during the Uralian orogeny. During the Caroniferous (350 mill years ago), rifting caused the formation of salt basins. Subsequent erosion and collapse of these orogenic belts produced an extensive shallow marine basin systems and delta deposits, and the Barents Sea area has been either an intra- or epi-continental sea since the late Palaeozoic. The structural geology of the Barents Sea is, therefore, a complex patchwork of basins and platforms, covered with thick layers of shallow marine sedimentary rocks from the late Palaeozoic onwards. Carbonates (limestone) and chert dominate the late Palaeozoic, with sands and shales dominating the Mesozoic and later rocks. Sedimentary rocks reach up 12km thick in the basins, with Triassic deposits alone reaching up to 8km thick (Dore, 1994).

Sedimentation and erosion patterns in the Pliocene (last million years) have alternated between strong localized erosion during glacial periods and slow marine sedimentation during inter-glacial periods. Seismic evidence indicates that the Barents Sea was completely glaciated several times during the Pliocene, with grounded ice reaching to the edge of the continental shelf at least 7 times (Andreassen et al., 2004). During the last ice age, which ended about 15,000 years ago, the Barents Sea was covered by grounded ice up to 2,000m thick. Ice cover in the Barents Sea was part of a larger ice sheet which covered north Russia, Scandinavia, parts of northern Europe, and possibly extending into the North Sea and northern and central Britain. The Barents Sea ice sheet was anchored to islands and shallow banks, with fast flowing ice-streams existing in major trough systems — a situation comparable to West Antarctic Ice Sheet today (Howell et al., 1999). Ice streams reached speeds of up to 1km/year, transporting considerable amounts of sediments off the continental shelf, resulting in the rapid growth of several large submarine fans, most notably at the mouth of Bear Island Trough (Howell and Siegert, 2000).

Marine life in the Barents Sea, as we know it today, stretches back to the end of the last ice age. There is a layer of post-glacial marine sediment deposited over older, pre-glacial sediments and bedrock. Thickness of this sediment layer varies over the entire sea, due to underwater topography, currents, and re-suspension. A major bottom mapping project, MAREANO http://www.mareano.no, is now in progress to produce detailed information on the structure and topography of the Barents Sea bottom and the benthic life.

2.3 Abiotic components

R. Ingvaldsen (IMR), A.L. Karsakov (PINRO), V.K. Ozhigin (PINRO), A.G. Trofimov (PINRO), and O.V. Titov (PINRO)

2.3.1 Meteorological conditions

Atmospheric forcing exerts influence on marine ecosystems through winds and air-sea interactions. Variations in large-scale atmospheric circulation cause changes in upper ocean circulation, ice extent, and hydrographic properties of the water column. Changes in marine environments in turn cause biological responses such as timing of spring phytoplankton bloom, zooplankton production, patterns of fish eggs and larvae drift, encounter rate of larvae and their prey, survival and recruitment (Ottersen et al., 2004; Rey, 1993; Skjoldal and Rey, 1989; Sundby, 1991; 1995; 2000).

The North Atlantic Oscillation (NAO) (e.g. Hurrell et al., 2003) is a predominant, recurrent atmospheric pattern of seasonal and long-term variability in the North Atlantic (Figure 2.3.1). However, climatic conditions of the Barents Sea are determined by both Atlantic and Arctic climatic systems, the winter NAO index explains only about 15-20% (R2=0.14-0.22) of interannual variability in air and sea temperature in the southern Barents Sea (Ozhigin et al., 2003).

During cold seasons, a typical feature of atmospheric pressure is a low-pressure trough stretching from Iceland to the central Barents Sea. Pressure lows frequently travel along it bringing warm air from the Atlantic towards Novaya Zemlya archipelago (Figure 2.3.2). The southern Barents Sea is usually dominated by southwesterly winds, which contribute to increased advection of warm Atlantic water into the area. In the northern part of the sea, cold northeasterly winds predominate.

During summer, contrasts in sea level pressure are pronounced over the northeast Atlantic (Figure 2.3.2). In both Norwegian and Barents Seas horizontal gradients of pressure are relatively small; as a result, light winds of different directions blow over the Barents Sea. In some years, cold northerly and northeasterly winds prevail – even in the southern part of the sea – during May-August.

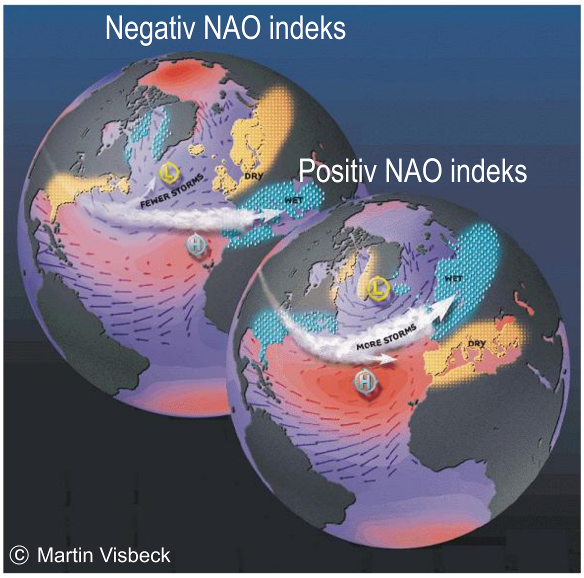

Figure 2.3.1. A positive NAO phase (bottom right globe) is characterized by a marked difference in air pressure between the low-pressure centre near Island and the high-pressure centre further south in the North Atlantic. In a positive NAO phase the dominating winds will be stronger than average and have a more northern displacement. This leads to more precipitation and higher temperature in Northern Europe. In a negative phase the difference in air pressure will be less and the west-wind belt will be weaker; thus generating opposite responses (graphics from Martin Visbeck, Lamont-Doherty Earth Observatory, USA).

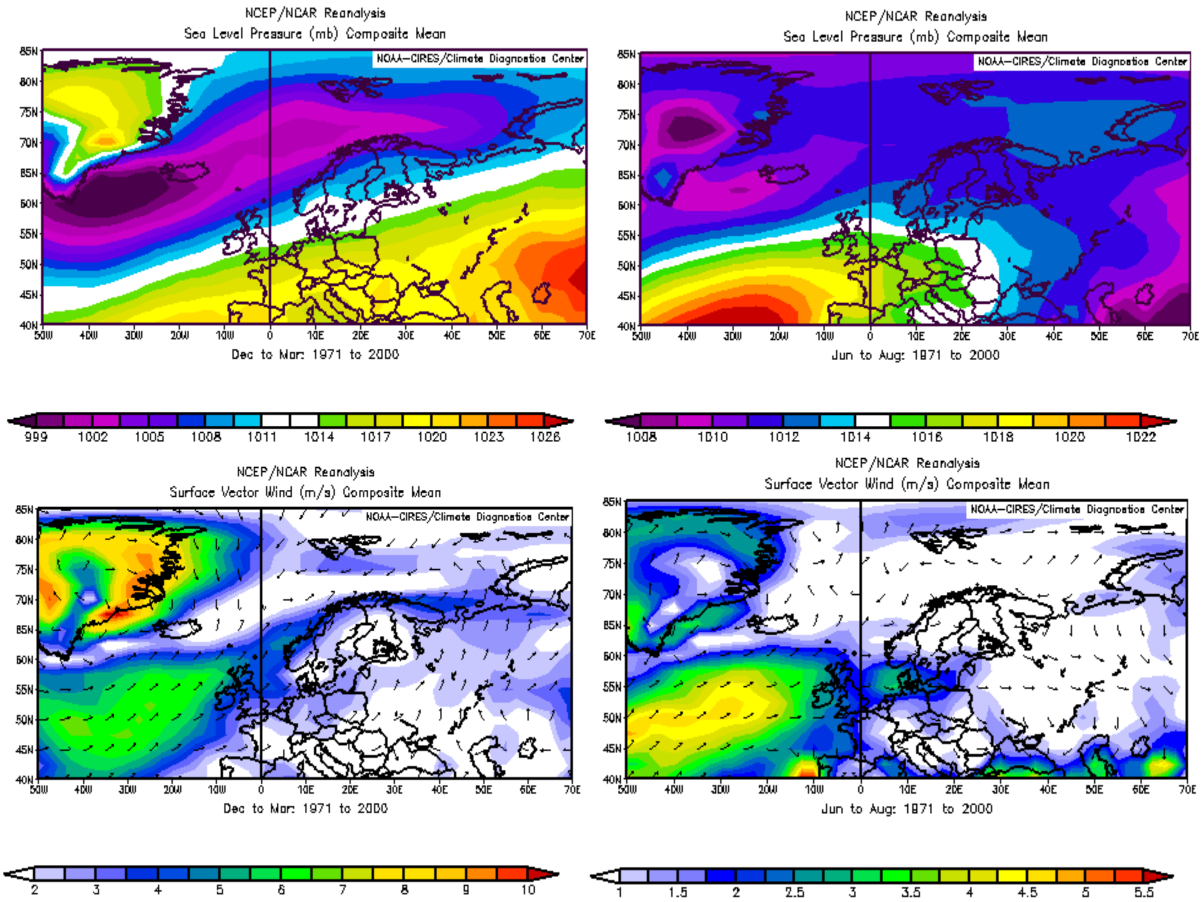

Figure 2.3.2. Long-term mean (1971-2000) sea level pressure (top) and wind vectors (bottom) during December-March (left plates) and June-August (right plates). Data source for sea level pressure fields and wind vectors: http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl.

Long-term seasonal mean sea level pressure patterns greatly influence the spatial variation of air temperature in the Barents Sea. Figure 2.3.3 shows the climatic seasonal cycle of air temperature at different stations around the Barents Sea: Svalbard Airport (78.2°N, 15.5°E), Bear Island (74.5°N, 19.0°E), Murmansk (69.0°N, 33.0°E), Malye Karmakuly (72.4°N, 52.7°E), and Heiss Island (Franz Josef Land Archipelago) (80.6°N, 58.0°E). The long-term mean air temperature over the Barents Sea ranges from -7 °C in the south to -25 °C in the north during January, and from 12 °C to 1 °C in corresponding regions of the sea during July (Figure 2.3.3).

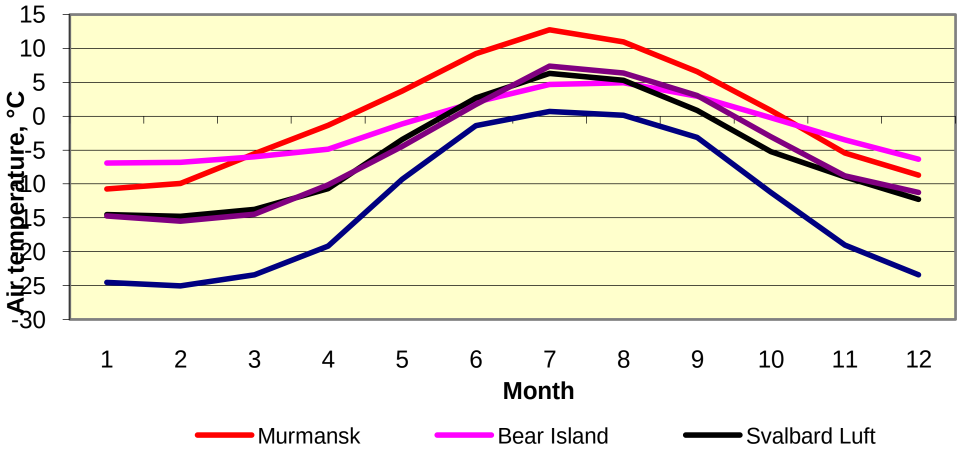

Figure 2.3.3. Climatic seasonal cycles of air temperature: Svalbard Airport, Bear Island, Murmansk, Malye Karmakuly (southern Novaya Zemlya archipelago), and Franz Josef Land (GMO Im. E.T.).
Data source: http://data.giss.nasa.gov/gistemp/station_data/.

2.3.2 Oceanographic conditions

2.3.2.1 General circulation

The Norwegian Atlantic Current carries warm and salty Atlantic water northwards along the Norwegian continental shelf break outside the Norwegian Coastal Current (Figure 2.1.1). When entering the Barents Sea it splits into two main branches. The first branch flows northeast along the Hopen Trench. The second branch flows eastward parallel to the coastal current towards Novaya Zemlya archipelago; this branch is called the Murman Current. Eventually, the modified Atlantic Water enters the Arctic Ocean between Novaya Zemlya and Franz Josef Land. The relative strength of these two branches depends on local wind conditions in the Barents Sea. Smaller Atlantic water currents also enter the Barents Sea from north-west region; they generally branch into subsurface flows, and do not extend very far south, but may have substantial impact on climate conditions in the northwestern Barents Sea.

The Norwegian Coastal Current flows close to shore, and eastward into the Barents Sea. It carries relatively fresh water from the North Sea, and the Norwegian river system. During winter this current is deep and narrow, during summer it is wide and shallow. Its temperature has a strong seasonal signal. Cold fresh Arctic water arrives mainly from the Arctic Ocean; it enters the Barents Sea between Nordaustlandet and Franz Josef Land, and between Franz Josef Land and Novaya Zemlya archipelago. The latter branch flows westwards across the northern Barents Sea, and along the eastern slope of Spitsbergen Bank where it joins the East

Spitsbergen Current. These two currents continue as the Bear Island Current, following the topography around Spitsbergen Bank into the Storfjord Trench, before it rounds the southern tip of West Spitsbergen through a narrow zone between land and Atlantic Water. Atlantic and Arctic water masses are separated by the Polar Front, which is characterised by strong temperature and salinity gradients. In the western Barents Sea the front position is stable; in the eastern Barents Sea the front position varies seasonally and inter-annually.

2.3.2.2 Currents and transports

Observed current in the Fugløya-Bear Island region is predominantly barotropic, and reveals large fluctuations in both current speed and lateral structure (Ingvaldsen et al., 2002; 2004). In general, the current is wide and slow during summer and fast, with possibly several cores, during winter. The volume transport resembles the velocity field and varies with season due to close coupling with regional atmospheric pressure. Numerical models forced with wind predict that southwesterly winds, which is predominant during winter, accelerates flow of Atlantic Water into the Barents Sea; whereas, weaker and more fluctuating northeasterly winds, common during summer, slows transport. The same conclusion is reached using current measurements in the exit area of northeast Barents Sea. Since 1997, monitoring transport of Atlantic Water into the Barents Sea indicates highly variable net transport that averages 2 Sv (Sv = 106 m3s-1). The average transport of Atlantic Water into the Barents Sea during 1997-2007 is 2.2 Sv during winter and 1.8 Sv during summer. During years in which the Barents Sea changes from cold to warm marine climate, the seasonal cycle can be inverted. Moreover, an annual event of northerly wind causes a pronounced spring minimum inflow to the western Barents Sea; at times even an outward flow.

Strong tidal currents, peaking at 80-100 cm/s in spring, are present on Svalbardbanken (Gjevik et al., 1994). In this area, the tide induces a residual current that forms an anti-cyclonic eddy between Bear Island and Hopen. The largest tidal amplitudes are found along the coast of Finnmark in Norway and Kola in Russia, where the amplitude extends up to 1.3 m. In the Hopen Trench there is a main amphidromic system (i.e. the tidal amplitude in the centre of the amphidromic system is approximately zero).

Heat transport into the Barents Sea is formed by a combination of volume and temperature of inflowing water masses, although these two factors are not necessarily linked. The reason is that while temperature of inflowing water depends on temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This signals the importance of measuring both volume transport and temperature, since volume flux is essential to transport zooplankton, fish eggs, and larvae into the Barents Sea.

Surface drift experiments have demonstrated large numbers of mesoscale eddies in the Barents Sea, particularly in the western region. Small eddies are generated both in the frontal area between Atlantic and Coastal Currents and along the shear zone between waters flowing in and out of the Bear Island Trench. Most of these eddies are limited in time and space, but may last for a month. Large eddies, generated by the local topography, have also been observed; examples are cyclonic (counter-clockwise) eddies at Ingøy Deep, and anti-cyclonic (clockwise) eddies at Central and Great Banks. Eddies prolong local residence time for organisms passively advected with currents, such as plankton and fish larvae.

Monthly wind-driven and total volume fluxes through sections crossing the main currents of the Barents Sea were calculated with a numerical model for 1971-2000. Seasonal variations in the wind-driven and total fluxes are shown in Figure 2.3.4 and Figure 2.3.5, respectively.

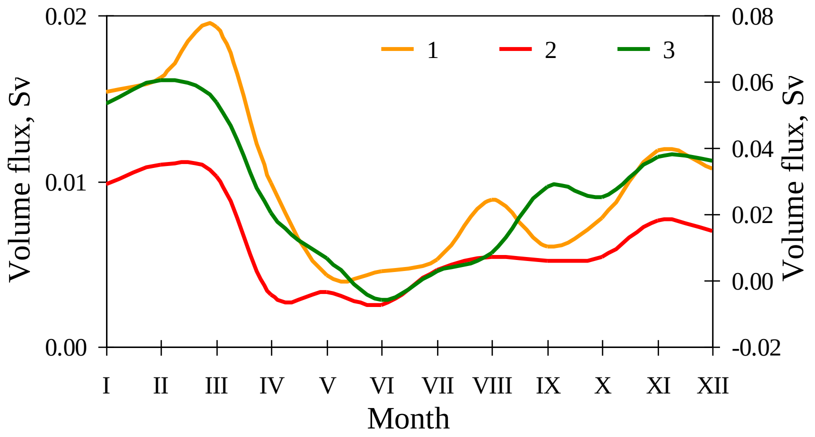

Figure 2.3.4. Seasonal variations in wind-driven flux through sections crossing the West Spitsbergen Current (1), North Cape Current (2, right axes) and Murman Current (3, right axes).

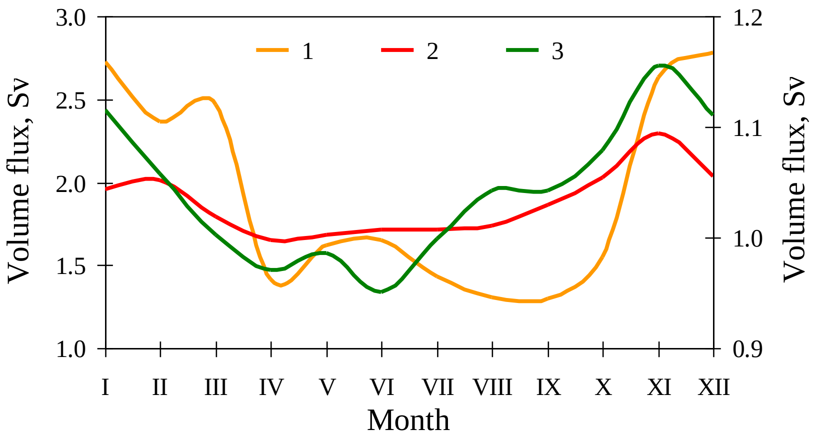

Figure 2.3.5.Seasonal variations in total flux through sections crossing the Spitsbergen Current (1), North Cape Current (2) and Murman Current (3, right axes).

Despite the fact that these curves have different shapes for different sections, the common features are easily noted. As a rule, the seasonal minimum is April-June for total flux and May-June for wind-driven flux, while the seasonal maximum is November-January for total flux and January-March for wind-driven flux.

2.3.2.3 Water masses and stratification

Atlantic Water is commonly defined as having salinity >35.0 and temperatures >3oC. Between Norway and Bear Island, the temperature of Atlantic Water varies seasonally and inter-annually from 3.5-7.5 ^{o}C. As a rule, both temperature and salinity decrease in northwards and eastwards in the Barents Sea (Figure 2.3.6). For this reason, water with salinity as low as 34.95 is often classified as water of Atlantic origin. In the southwestern Barents Sea, Atlantic water is normally predominant. Interannual temperature variation in the Barents Sea is illustrated in Figure 2.3.7, which presents annual temperature observations during the last 100 years for the Kola region (Bochkov, 1982; 2005) in the southern Barents Sea.

Coastal Water resembles Atlantic Water but generally has lower salinity (<34.7) and a wider temperature range, particularly near the surface. Arctic water is characterised by low salinity, but is more easily classified by its low temperature. The core of the Arctic Water has temperature <–1.5 ^{o}C and salinity between 34.4 and 34.7.

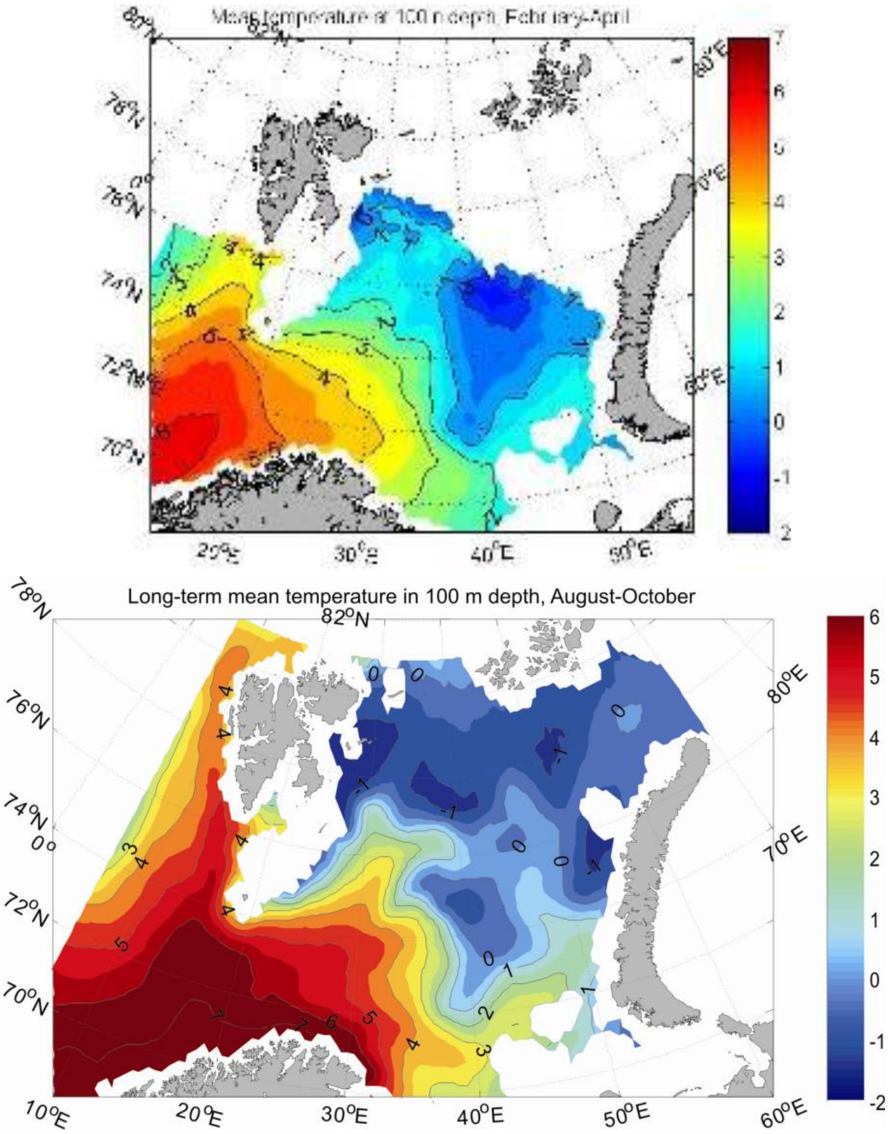

Figure 2.3.6. Average temperatures in the Barents Sea at 100 m. Based on observations during February-April (upper) and August-October (lower) for the period 1977-2007. During any specific year the Polar front is quite sharp; this is not evident in the figure due to winter ice cover (that limits collection of data in northern areas) and interpolation effects.

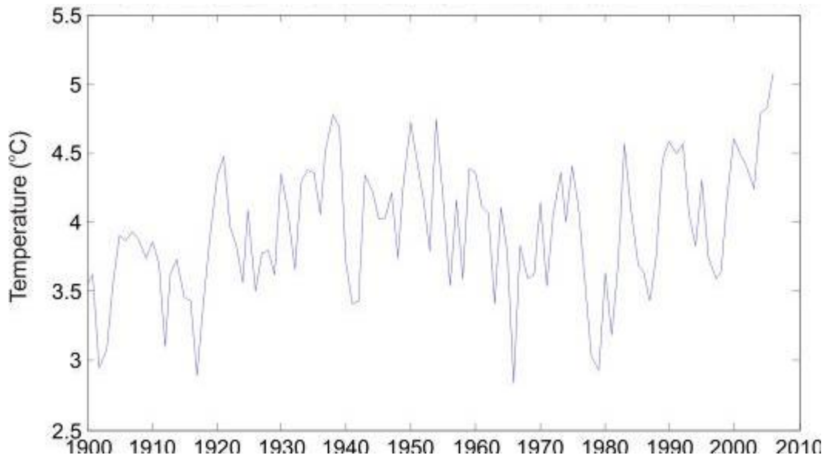

Figure 2.3.7. Average annual temperature between 0 and 200 m depth in the Kola region, stations 3-7 (Bochkov, 1982, 2005; www.pinro.ru).

The seasonal ocean temperature signal is strong, and lags behind air temperatures by 2-3 months (Figure 2.3.8). Maximum values are reached during September-October and minimum values during March-April.

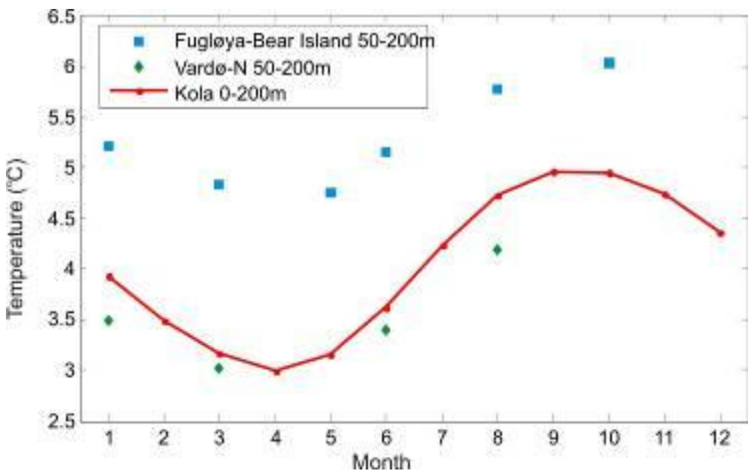

Figure 2.3.8. Climatic seasonal cycle in the southern Barents Sea. For Fulgøya-Bear Island and Vardø-N the ocean temperatures are between 50 and 200 m, for Kola temperatures are between 0 and 200 m..

Temperature in the upper 150 m layer of the water column reaches a seasonal minimum during April in the Kola region; this minimum occurs a bit later in deeper layers. The corresponding time delay – to reach a seasonal maximum temperature in deeper layers – is longer. In the upper 20 m layer of the water column, the seasonal maximum takes place in August; the timing is then gradually delayed with increasing depth. As a result, the time of temperature maximum near-bottom is between October and January (Figure 2.3.9).This phenomenon was first noted by N.M.Knipovich (1906), and later described by many researchers (Sarynina, 1980; Tereshchenko and Bochkov, 1994; Tereshchenko, 1997; 2000; Boitsov, 2006).

Seasonal variation of salinity in the Kola region differs from that of temperature. Salinity variation in the upper 50 m layer of the water column has a minimum during August-September and a maximum during January-April. Northern stations of this region are an exception; there the seasonal maximums at depths extending down to 50 m occur during

December. The seasonal signal at lower depths and/or near-bottom layers has not been determined; long-term data indicate that at such depths salinity stays constant year round (amplitude of the change is less than 0.05) (Figure 2.3.9) (Karsakov, 2007).

Different processes – both external and local in origin – operating on different time scales, determine temperature regimes in the Barents Sea: advection of warm Atlantic water masses from the Norwegian Sea, temperature of these water masses, local heat exchange with the atmosphere, and differences in water density within the ocean itself. Inflow from the Norwegian Sea into the Barents Sea is influenced by wind conditions in the western Barents Sea, which again is related to wind conditions in the Norwegian Sea (Ingvaldsen et al., 2004). Both slowly moving advective propagation and rapid barotropic responses due to large-scale changes in air pressure must be considered when describing variation in temperature of the Barents Sea.

In ice-free waters, winter is characterised by an intense deep vertical mixing, which brings mineral nutrients to the upper layers of the water column. In late spring, the upper layer becomes stratified, which strongly impacts timing and development of the spring bloom. Different water masses differ considerably in terms of mixing and stratification.

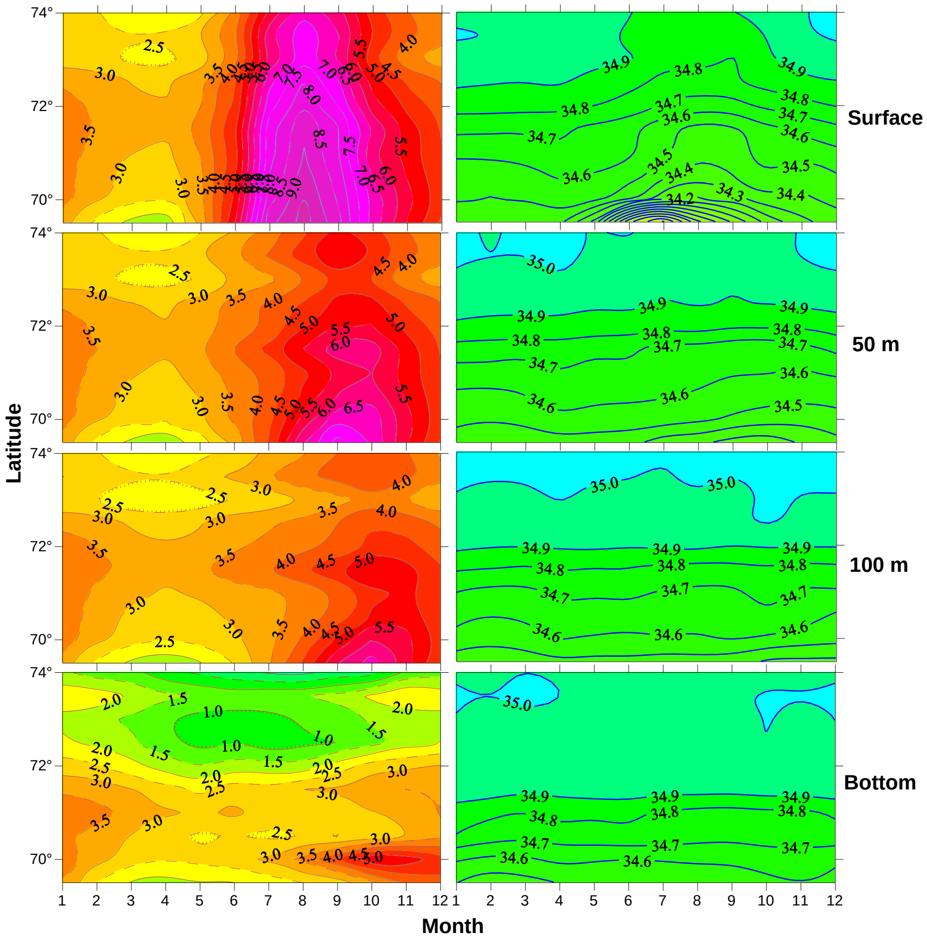

Figure 2.3.9. Seasonal variation of the long-term mean temperature (left panels) and salinity (right panels) at sea surface, 50 m, 100 m and near-bottom depths in the Kola region.

2.3.2.4 Ice conditions

The Barents Sea is characterised by large inter-annual variations in ice conditions. Variability in ice coverage is linked to quantities of inflowing Atlantic water, the northerly winds (Sorteberg and Kvingedal, 2006) and import of ice from the Arctic Ocean and the Kara Sea. The ice has a relatively short (1-2 year) response time to temperature changes in Atlantic water; distribution of sea ice in the eastern Barents Sea usually changes a bit later than in the western part. Since the late 1960s, a decreasing trend (3.5% per decade) in the extent of sea ice has been observed. Since 2005, an extreme ice minimum has been measured in the Barents Sea.

Estimates of the long-term mean ice edge indicate maximum ice coverage in the Barents Sea in mid-April, while minimum ice coverage is observed at the end of August through the first half of September. In warm years, there can be no ice cover at all during August-September; whereas in cold years ice coverage – primarily in northern regions – can measure 40-50% during the same months. At the end of severe winters, ice coverage can be above 90%; whereas during warm winters, ice coverage may not exceed 55-60% even in April.

During winter, sea ice spreads from north to south and from east to west. This process lasts through the end of April. Even during May-June, the ice edge is located along the western coast of Novaya Zemlya archipelago. Warm waters of the Novaya Zemlya Current enter the northeastern extent of Barents Sea, and form a hollow in the ice edge in the direction of inflow. Through October, the ice edge may continue to retreat northward and eastward (Zubakin, 1987) (Figure 2.3.10).

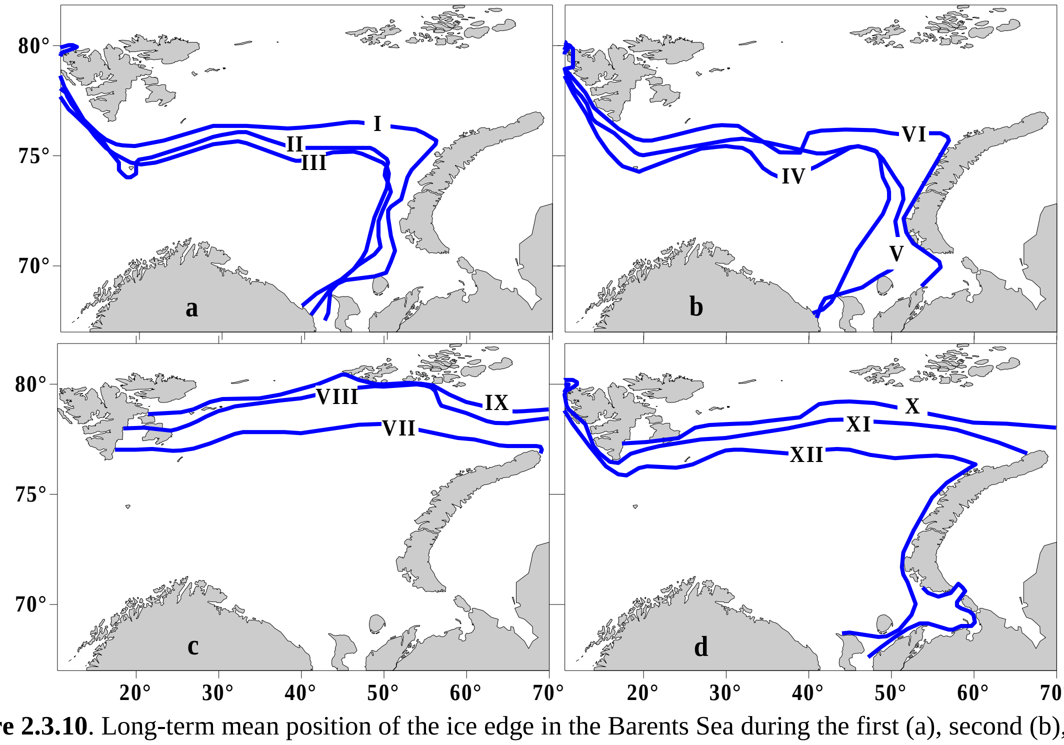

Figure 2.3.10. Long-term mean position of the ice edge in the Barents Sea during the first (a), second (b), third (c) and fourth (d) quarters.

At the end of winter the ice thickness in the near-edge zone usually does not exceed 30 cm, and it may not form as a single ice field, but rather in a pattern of broken ice. During winter, the thickness of drift ice in the southeastern Barents Sea may reach 70-80 cm. By the end of winter, the thickness of maximum ice cover may reach 130-150 cm in the northern Barents Sea, where large ice fields and their fragments dominate. Under the influence of wind, currents, and tides, there may be frequent ice movement; ice fields often break up, and form hummocks before freezing together again. Icebergs often separate from glaciers of the Franz Josef Land and Svalbard archipelagos in the northern Barents Sea.

2.3.2.5 Chemical conditions

Space and time distributions of oxygen in the Barents Sea are determined by the geographical location of the sea, bottom topography, water exchange with adjacent seas, river run-off, photosynthesis, organic matter destruction, other biological and biochemical processes. Physical processes determine oxygen regime in the Barents Sea during the polar night; they determine variation of dissolved oxygen content in sea water. Biological and biochemical processes are of great importance during warm seasons, and determine variation of oxygen saturation of sea water.

During winter, the maximum oxygen content is observed where water temperature is lowest and oxygen saturation of the whole water column is below 100 %. During spring, surface water masses are oversaturated with oxygen in most of the Barents Sea, and in May, oxygen saturation can reach 105-115 % and the oxygen content is 8.0-9.5 ml/l. During summer and autumn, oxygen content distribution is gradually becoming like temperature distribution. During September, oxygen saturation of sea water in the photic layer (up to 20-50 m) is 100-105 % (Titov and Nesvetova, 2003) (Figure 2.3.11).

Oxygen saturation of the near-bottom layer in the Kola region is used for monitoring of long-term variations of oxygen content, because variation of oxygen content is closely raleted to variation of water temperature, and oxygen content in the surface layers is subjected to significant seasonal variations.

According to the data presented in Figure 2.3.12, space distributions of oxygen saturation of water masses in the Barents Sea and in the Kola region agrees rather well. For example, during 1967-1970 and 1979-1983, when oxygen saturation anomalies in the Kola region were on average -1.4 % and -1.1 % respectively, oxygen saturation of the near-bottom layer in the most of Eastern Basin was on average 82-85 %. During 1971-1975 and 1984-1988, oxygen saturation anomalies in the Kola region were 0.7 % and 0.6 % respectively, and oxygen saturation of the near-bottom layer in Eastern Basin was 87-92 % (Figure 2.3.12).

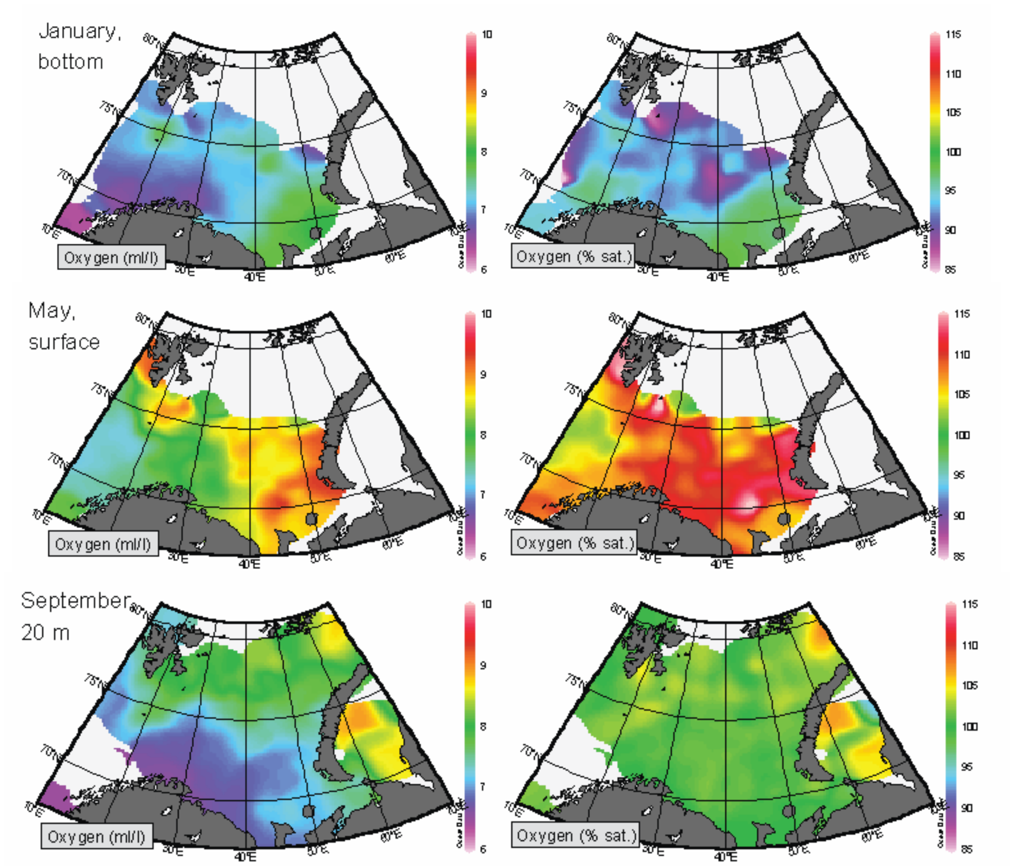

Figure 2.3.11. Long-term mean distribution of oxygen in the bottom layer in January (upper row), in the surface layer in May (middle row), and in the surface layer in September (lower row).

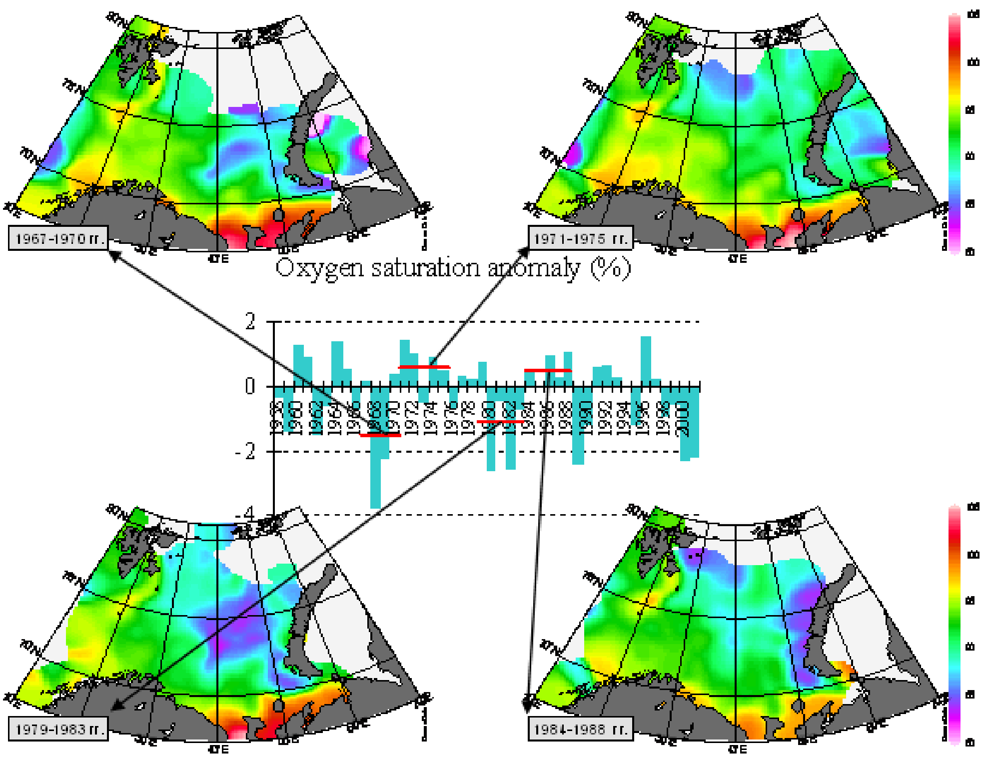

Figure 2.3.12. Long-term variation of oxygen saturation of the near-bottom layer in the Barents Sea and in the Kola region (centre).

2.4 Biotic components

2.4.1. Bacteria and viruses

Y. Børsheim (IMR), K. Sokolov (PINRO), O. Titov (PINRO)

In the biogeochemical cycles of the ocean, a multitude of processes are catalyzed by Bacteria and Archaea, and the functioning of these cycles in the Barents sea do not differ qualitatively from those at lower latitudes. The carbon cycle may well serve as an example of the biogeochemical cycles (Figure 2.4.1). The heterotrophic procaryotes, denoted bacteria for simplicity, are the major degraders of dissolved organic carbon (DOC), which is their principle source of energy and carbon. At high latitudes, DOC accumulates in the photic zone during the productive season, and the concentration decreases in September/October due to the 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 from organismal carbon in the primary producers into the pool of DOC (Børsheim et al., 2005). Grazing and predation produces form fecal material which may be released as DOC, or occur as pellets. Fecal pellets may sediment to the seafloor or sometimes getting dissolved in the water column as DOC. The shelf basin of the Barents Sea is fairly shallow and the water column mixes from surface to bottom during winter at many parts of the basin. Therefore resuspension of sediments and leaching of DOC accumulated in sediments provide an additional source of DOC in the Barents Sea, presumably mostly during winter. Figure 2.4.2 shows concentrations of DOC in the Northwestern Barents Sea July-August 1996. High values in the upper 100 meters are DOC accumulated during the productive season, and the high values in the deeper part are presumably a result of sediment resuspension and leaching.

For qualitative specification and overall biomonitoring of aquatic environments estimation of functional activity and reconfiguration of bacterial complex is a critical aspect.

Bacterioplankton from eutrophic areas of the world's oceans including waters of the Barents Sea is characterized by a wide range of abundances, as well as high variability in structure and functional rates (Teplinskaya, 2001). The total bacterial abundance in the south-eastern sea varies from 1. 4·105 to over 106 cells per ml. The highest total bacterial abundance is in the coastal areas and zones having water masses with different characteristics. Vertical distribution of bacterioplankton is tesselated, with increased abundace in the thermocline layer at the depth of 30 m or lower, in 30-50 m layer. Values of the total abundance and bacterial biomass can vary during the year twice in the mean, with maximal rates observed in spring-summer, and minimal – winter and autumn (Baytaz and Baytaz, 1987; 1991; Teplinskaya, 1990; Mishustina et al., 1997).

Parasitism by viruses also constitutes a source of DOC. This is illustrated by the reproductive cycle of the lytic bacteriophages, which are viruses parasitizing bacteria (Figure 2.4.3). After infecting a bacterial cell and multiplying within the cell at the cost of the bacterial metabolism, the host cell is destroyed in order to let the viral particles to be released to 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 virus attacks Brussard et al., 2007; Frada et al., 2008; Marcussen and Have, 1992). Although the bacteriophages have the most extreme effect in that they can completely destroy their hosts, the effect of killing hosts with subsequent release of organic substrate for bacteria is a general consequence of viral infectivity.

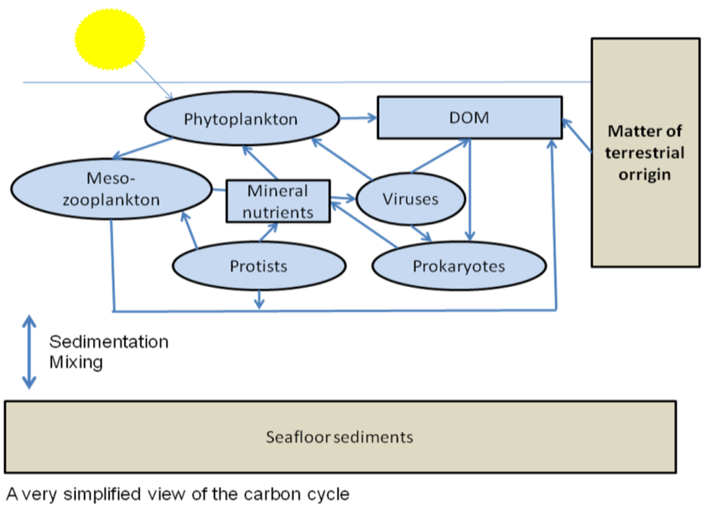

Figure 2.4.1. A box diagram showing major pathways in the biogeochemistry of carbon.

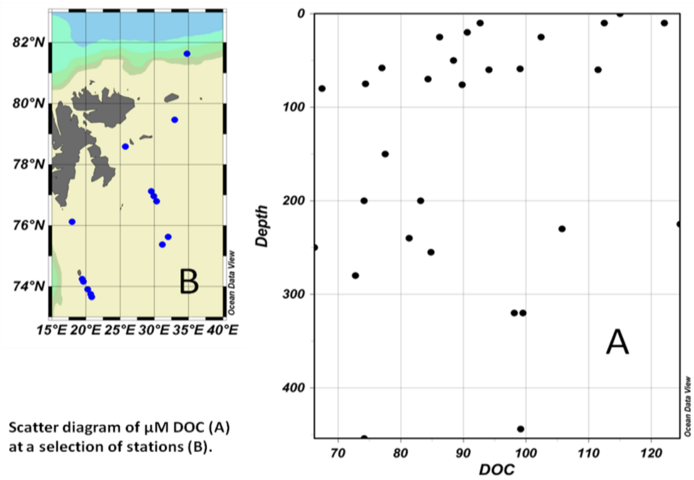

Figure 2.4.2. Dissolved organic carbon (DOC), synonymously denoted DOM, is a term for the sum of all dissolved organic substances present in a water parcel. The number of compounds that constitute DOC is unknown, and even the distribution into classes of organic substances is only partly characterized. In the current context DOC is of interest mostly because the bacteria are the only organisms that assimilate and use DOC efficiently as sources of energy and carbon.

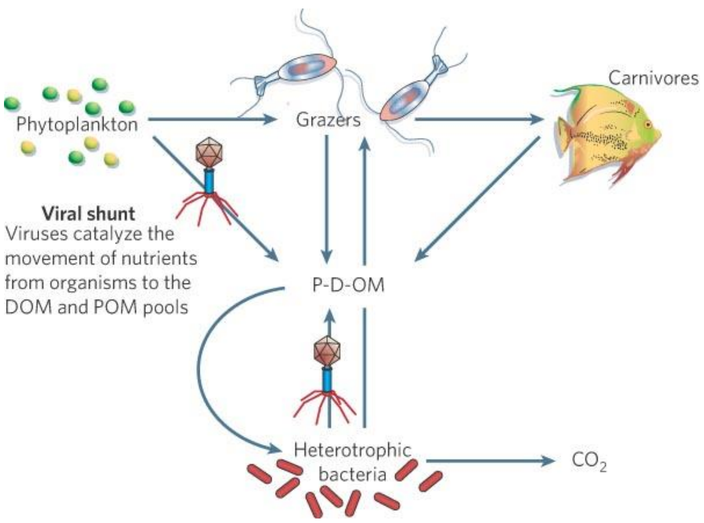

Figure 2.4.3. Illustrative cartoon of some ineractions between viruses and the ecostystem. Reprinted by permission from Macmillan Publishers Ltd: Nature C (Curtis A. Suttle (2005) Viruses in the sea. Nature 437:365-361). Viruses short-circuit the flow of carbon and nutrients from phytoplankton and bacteria 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.

For the viruses, the probability of finding a host to infect is dependent on the concentration of hosts. Therefore more dense populations are more likely to suffer from epidemic viral infections than rare populations. The concentration effect on microbial population dynamics has been coined the "killing the winner" hypothesis (Thingstad and Lignell, 1997). The populations that are successful in terms of nutrient acquisition and fast growth will increase their abundance consequently also the probability of propagating their viral parasites. The logical prediction of the hypothesis is that viruses are important in keeping diversity high.

Virus existence seems to incorporate the ability to snatch genes from their hosts, and from other viruses, and transfer them along for benefit of their own existence (Mann et al., 2005).

In addition, sometimes genes from viruses happen to be incorporated in the genomes of their hosts, and it is currently believed that such horizontal transfer of viruses between not 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 that are transported by viruses are factors of pathogenic ability and have been extensively studied. 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 of humans (Waldor and Mekalanos, 1996).

The numbers of viruses are in every way staggering. Counted in the microscope, the virus numbers normally exceed bacterial number roughly by a factor of ten. Measured as genotypes, which is a fair proxy for species, there are more than 5000 different types in 100 litres of seawater. In a kg of sediment the number may be around a million (Breitbart et al., 2002; 2004). What is even more intriguing than the diversity of viruses is the diversity within their individual genomes. Clearly every genotype consists of a mosaic of gene sequences with a variety of ages and origins (Dinsdale, 2008).

Both bacteria and viruses show highly variable abundance in the Barents Sea (Figure 2.4.4). A transect in midsummer showed that the concentration of viruses varied from 5·108 to 9·109 particles per litre, and bacterial total counts varied from 5·108 to 6·109 cells·l-1 (Howard-Jones et al, 2002). The viral abundance covaried to a fair degree with bacterial abundance, except for the station farthest north which was ice-covered. Thus in general the dynamics of bacteria and viruses in this area do not differ from other parts of the ocean, but the situation in the ice-covered areas in the north remains to be investigated.

Data on current situation on bacteria and viruses in the Barents Sea is scarce, and is therefore not addressed in Chapter 4.

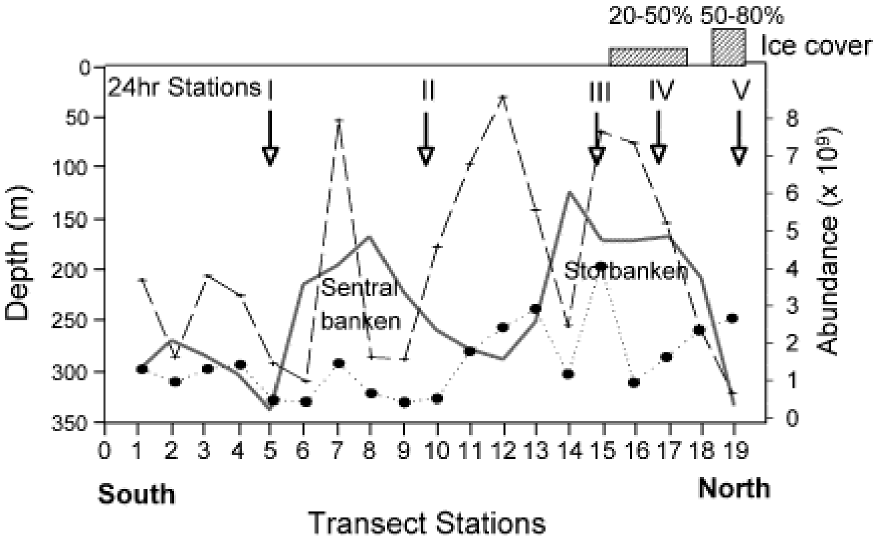

Figure 2.4.4. Results from a south to north transect in the Central Barents Sea in June-July 1999 (From Howard-Jones et al. 2002). Bacterial (●) and viral (–) abundance presented as cells or VLP per litre across the Barents Sea. Stations 1–10 are the southern and central Barents Sea, stations 11–14 in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

2.4.2 Phytoplankton

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As the main primary producer, phytoplankton is an important link between the physical and chemical elements and higher tropic levels in the marine food web. Changes in the environment could affect the annual succession and species composition of the phytoplankton, as well as the overall primary production in the area. Phytoplankton monitoring will give important information regarding biological changes on the lowest level in the food web with environmental impact and climatic changes.

The variability in the timing and development, abundance and species composition is large in the Barents Sea. This is due to the large gradients that are observed in the physical and chemical environment along east – west and north – south gradients in the area. The horizontal distribution (Biogeography) of phytoplankton in the Barents Sea is in large degree controlled by the polar front, freshwater runoff and ice cover and ice melting. The Arctic water and the Atlantic water will bring characteristic species into the Barents Sea, as well as the coastal water, all contributing to the diversity in the area. In the Barents Sea phytoplankton species of Arctic origin, cosmopolite, and boreal origin is observed. However, the percentage of the different groups will vary considerable depending on the location of the study site within the Barents Sea.

According to the traditional views of classical marine ecology (Usachev, 1935; Shirshov, 1937; Raimont, 1983; and others), the entire process of development of the phytoplankton, and their qualitative and quantitative characteristics, is fully determined by direct impact of abiotic factors, such as light, ice conditions, temperature, salinity, and concentration of macro and micro nutrients. However, M.M.Kamshilov (1961) suggested that the main factor, defining the structure and functioning of pelagic ecosystems, is the biotic interactions between organisms. The reality is processes and evolution driven both by bottom-up (environmental) and top-down (biotic interactions/predation) forces. The strength and importance of the different factors, physical, chemical, and biological, will vary during the different phases, e.g. high grazing pressure during summer and stratification during spring. Obviously, with such a tight connection between the components of the community, it is not sufficient to use one or a few indicators to obtain reliable results of its condition. Such criterion should have a complex character and reflect all the ongoing processes, as well as to be relatively stable in time and space and keep this stability in the constantly changing natural environment. In the future monitoring and research program it will be important to seek for new and better indicators or criterions for the pelagic phytoplankton.

2.4.2.1 Species composition and diversity

At the moment, there are 307 distinguishable species of pelagic micro algae registered in the Barents Sea, not including multiple subspecies and varieties (Makarevich, Larionov, 1992; Matishov et al., 2000). Taxonomically, 7 of them belong to the golden algae, *Cryophyte*, 148 – diatoms, 123 – dynophytes, 5 – green algae, 4 – to *Haptophyta* division, 8 – to *Prasinophyta* division and 6 species – to *Euglenophyta* and *Cryptophyta* algae. 49 species (16%) are oceanic, 178 (58%) – neritic, 39 (12.7%) – panthalassal species, 17 (5.5%) can be clearly defined as a fresh water species, however, they are typical representatives of the Barents Sea pelagic algae flora, abundant in estuaries and even in the open sea. 14 species (4.6 %) do not represent typical planktonic species, but belong to the microphytobenthos; however, they are regularly registered in the pelagic coastal zone and thus can be included in the list. Other species can’t be given an ecological characteristic. Presently, according to the phytogeographical affinities, 119 (38.8%) species of the Barents Sea phytoplankton can be characterized as Arctic, 67 (21.8%) – boreal, 91 species (29.6%) – cosmopolitan, and no defined geographical affinity has been found for the rest of the species (Matishov et al., 2000).

Studies with high taxonomical resolution should be repeated with some years apart. Changes in the environment, e.g. temperature, current pattern or increase in nutrients, most likely will influence on the species composition or alteration in the portion of phytogeographical affinities. Increase in the sea temperature would most likely result in new species appearing in the Barents Sea.

2.4.2.2 Seasonal succession

According to several studies, general structure of the succession cycle of phytoplankton in the Barents Sea could be split up into different phases covering a time period of the year. These phases will be the winter phase (low activity), spring phase (covering the onset of and spring bloom maximum), summer phase, and the autumn phase. These periods shows characteristic species composition, abundance, and production.

It must be taken into consideration that due to the size of the Barents Sea area (large gradients east – west and north – south), the process of succession stages might not proceed the same way in all areas. Therefore, this selection of seasons over the entire Barents Sea can have only very general character. There will be interannually, as well as local, differences in the onset and duration of the different phases. There will also be differences in the species composition and biomass in different areas, but in most cases the taxonomical groups, even genus, will be similar over large areas.

In this general description of the succession the main focus is on the larger phytoplankton forms, such as diatoms and dinoflagellates. A group of the phytoplankton that is most likely underestimated in today's monitoring program is nano- and pico-plankton flagellates, most likely due to methodological difficulties in covering all groups with one standard method. These groups are however found frequently all year around showing a annual pattern in abundance and with variable auto- and heterotroph composition. The larger phytoplankton groups like diatoms and dinoflagellates make up most of the variability and dynamics and dominate during blooms (Ratkova and Wassmann, 2002).

2.4.2.3 Open water and ice edge zone

During the winter phase from November to February, there is low diversity and low production, with chlorophyll concentrations close to zero. The lowest levels are found in the ice free areas in the northern parts. During this period there are sufficient nutrients for growth, but the absent of clear stratification and light prevent large production. The species that are present are cosmopolitan representatives of dinoflagellates (*Dinophyceae*), large armed forms as *Protoperidinium*, *Ceratium*, *Dinophysis* (*Protoperidinium depressum*, *Ceratium longipes*, *Ceratium tripos*, *Dinophysis norvegica*) and athecate forms from the genus *Gymnodinium* and *Gyrodinium* and occasionally diatoms (*Bacillariophyceae*).

The spatial distribution of the phytoplankton in this period shows maximal abundance near the edge of ice formation in the open waters of the Barents Sea (Ryzhov, 1985). This fact has been causing debates among the specialists regarding the reasons for such distribution. This question has an important theoretical meaning for the explanation of so called "edge bloom" of microalgae.

The spring phase, from March to late May (early June), could be divided into two periods. In the early spring (March) the water masses is still mixed; there are adequate levels of nutrients, and enough light penetration for primary production. The main bloom does not appear, however, before the water shows some degree of stratification. Stratification of water masses in different parts of the Barents Sea occurs in different ways and will appear at different times. During this early period there is an increase in the phytoplankton population, dominated by neritic diatoms in the open areas of the Barents Sea.

Back in the end of the 19th century, the first Arctic researchers observed a high concentration of pelagic microalgae near the ice edge and under the ice. That fact led to the multiple hypotheses on the "ice-edge" bloom and processes that take place in this particular biotope, as well as the “start” of the spring bloom of phytoplankton in the northern seas. The earliest activity of phytoplankton occurs near the border of the ice cover, in stratified water masses. However, this link between the mass development of microalgae and ice edge is not always the case and is not observed in all areas of the Barents Sea. The early phytoplankton production could also take place in the polar front zone and in coastal and estuarine areas.

There has been some attention paid to the so-called ice algae – a specific community of microalgae, living within the layer of sea ice and possibly playing an important role in bioproductivity processes in the Arctic marine ecosystems (Alexander, 1974; Melnikov, 1989). However, there has been some discussion about the overall significant of this production in the Barents Sea. Most likely this communities are important on small scales, where as their contribution to the overall primary production is low (Kuznetzov and Shoshina, 2003). Hegseth (1998) estimated the ice algal production to comprise 16-22% of the total annual primary production in the ice-covered regions of the Barents Sea.

A stronger stratification of the water masses result in a rapid increase in the phytoplankton biomass in the surface water – spring bloom or spring maximum period. This period is characteristic by high abundance of phytoplankton, both as chlorophyll a and numbers of cells, and large diversity in the phytoplankton. The point in time of the spring bloom will vary considerable within the Barents Sea and between years. In some areas and years it could start as early as early April other years as late as early June. Species, forming the first peak of the spring bloom, are *Thalassiosira cf.gravida*, *T. nordenskioeldii* , *Chaetoceros socialis* , *C. furcellatus*, *Navicula vanhoeffenii*. In addition, during this period there is often an intensive bloom of the golden algae *Phaeocystis pouchetii* , and it can reach high quantity and biomass, being a important part of the spring maximum (highest recorded quantity and biomass – 8 mln cell/l and 1.7 mg/l respectively) (Druzhkov and Makarevich, 1989). In some years and areas the first spring peak could be followed up by a second peak. This shows lower density as is composite by other species of diatoms, often from the genus *Thalassiosira* and *Chaetoceros*, in additions to *Phaeocystis pouchetii*, taking please late in May.

The summer phase, from June to the end of August, is characterized by low to moderate density of phytoplankton. The typical spring species disappear and summer community of diatoms and dinoflagellates takes over (*Protoperidinium depressum*, *Ceratium arcticum*, *C. fusus*, *Leptocylindrus danicus*, *Leptocylindrus minimum*, *Skeletonema costatum*, *Chaetoceros decipen*s, and *Chaetoceros laciniosus*). This composition starts with diatoms and is gradually taken over by the dinoflagellates. During the summer phase, smaller blooms of flagellates and diatoms could be observed. In the later years blooms of the *Coccolithophyceae Emiliania huxleyi* has been observed in blooming concentration in the open areas. The phytoplankton shows biomass and distribution in a mosaic pattern during the summer period, with the highest abundance and diversity is observed in coastal waters and inn front system.

In august- September the biological summer is ended and the phytoplankton community goes into an autumn phase that could last until mid November. The biomass and diversity of phytoplankton will gradually decrease during this period, until it reaches a winter level in

November. The community is a mix of diatoms (*Thalassiosira*, *Chaetoceros*, *Rhizosolenia*, *Nitzschia*, *Rhizosolenia*) and dinoflagellates (*Protoperidinium*, *Gyrodinium*, *Dinophysis*, *Ceratium*). Dinoflagellates will gradually become more abundant. In some years high abundance of smaller flagellates is registered late in this period.

2.4.2.4 Coastal water

Phytoplankton production in the coastal water is to a large degree influenced by local hydrologic and meteorological factors, including fresh water runoff, wind mixing, tidal regime, as well as ice melting in the coastal areas. As for the open ocean the annual phytoplankton cycle could be divided into phases (winter, spring, summer, and autumn) as for the open areas. Along the Barents Sea coastal line there is large variation in the onset of the different phases along the Russian and Norwegian coast.

During the winter phase (November – mid March) the biomass and diversity of the phytoplankton is low and highly mosaic spatial distribution in abundance and biomass of microalgae (Druzhkov et al., 1997). The dominating group of the phytoplankton is diatoms, often a mix of pennales and centric forms in some areas, whereas dinoflagellates are more common in other. It is likely that also pico- and nanoflagellates are present in this period.

During the spring phase (mid March to early June) there is an increase in the phytoplankton biomass. The spring bloom will start as soon as the water column shows some degree of stratification. The start point of the spring bloom varies from year to year. It may start early, peaking at the end of March, or later peaking in May or even as late as early June. However, in generally the spring bloom maximum occur during April and early May. During the spring bloom the dominating phytoplankton group is diatoms. The bloom could be dominated by several species and different species could be dominating in different areas. There could also be differences between years in dominating species.

In some areas, there is a clear development in the diatom community with some species following others. Species that is dominating during this spring period will be *Chaetoceros curvisetus*, *C. furcellarus*, *C. diadema*, *C. holsaticus*, *C. socialis*, *Chaetoceros contortus*, *C. debilis*, *C. decipiens*, *C. Diadema*, *Navicula vanhoeffenii*, *N. pelagica*, *Nitzschia grunowii*, *Thalassiosita gravida*, *T. hyalina*, *T. nordenskioeldii*, *Thalassionema nitzschioides*, *Fragilariopsis oceanica* and *Skeletonema*. In addition to diatoms, the haptophyte *Phaeocystis pouchetii* could contribute significant to the total spring bloom biomasses in some areas. However, in most cases Phaeocystis forms blooms a short period after the main top of the spring bloom. In some areas there is a marked second spring bloom in June, often connected to fresh water runoff from land. This bloom varies every year in timing, in quantitative characteristics and in qualitative composition. In the end of the spring period, as the diatom biomass decrease, flagellates are dominating and *Pyramimonas* and cryptomonads (e.g. *Plagioselmis* spp. and *Teleaulax acuta*) have their yearly maximum in June together with other naked flagellates. The dinoflagellate *Heterocapsa rotundata*, *Protoperidinium depressum* and small naked dinoflagellates are also common in this post blooming period.

As the phytoplankton community enters the summer phase (June to the end of August) the abundance is reduced and new species are coming in. In this period there are large differences between sampling areas, with a high degree of mosaic in the phytoplankton horizontal distribution. In some sections diatoms (Pseudo-nitzschia “delicatissima type”, *Skeletonema*, *Chaetoceros contortus*, *C. laciniosus*, *C. diadema*, *Chaetoceros wighamii*, *Dactyliosolen fragilissimus*, *Leptocylindrus minimus*, *Leptocylindrus danicus*,*Thalassionema nitzschioides*) are dominating and forming smaller blooms. In other areas dinoflagellates, such as small athecate dinoflagellates (<20 µm), several species of the genus *Protoperidinium*, *Scrippsiella trochoidea*, *Heterocapsa triquetra*, *Prorocentrum minimum*, are more prominent. Smaller flagellates will also be an important part of the phytoplankton community. Later in this period (July-August) dinoflagellates become more common along the coast, especially species in the genus *Ceratium* and *Dinophysis*. In the later years large blooms of *Emiliania huxleyi* has been observed in July-August, covering large areas along the Norwegian Barents Sea coast.

During the autumn phase the biomass and diversity decrease until it reach winter situation during November. The phytoplankton community is dominated by dinoflagellates (*Ceratium* sp, *Dinophysis* spp, *Scrippsiella* sp and *Protoperidinium* spp). Even though the phytoplankton biomass is decreasing during this phase, some species of *Ceratium* might form high biomass blooms during August in some coastal areas. Generally diatoms are few in autumn, but in early autumn *Chetoceros affinis* and *Proboscia alata* may be of some importance.

Vertical distribution of phytoplankton during the whole year depends on the density of water mass: in the autumn-winter period, when seasonal pycnocline is absent, pelagic micro algae are evenly distributed along the entire water column; during the spring bloom, the center of the community is localized on the surface horizon; once the summer stratification is established, maximal abundance of phytoplankton occurs at the depth of 15-20 m, placed right above the pycnocline (Druzhkov et al., 1997; Larionov, 1997). In autumn-winter during period of absence of seasonal pycnocline, the phytoplankton is distributed evenly in the water column from the surface to the depth of main pycnocline bedding.

As mentioned above, this succession cycle is characterized by high stability despite annual climatic variability (warming, cooling, etc). Even more so – those deviations in cycle that are observed in different geographical regions of the sea don’t affect its main structure, and differences are only due to the terms of the start and length of the hydrological seasons. However, this conclusion is fully valid only for the open part of the Barents Sea. Data, presented above, shows that phytoplankton in the coastal areas shows significant variations.

Even more variations in the seasonal succession are found in estuarine areas (Kola gulf, Pechora bay, etc). Apparently, microalgal communities of the open waters have a strong developmental dependency on changes in the “global” climatic and oceanological factors (level of insolation, sea ice dynamics, and water mass distribution). While in estuaries, the main role belongs to the local processes – tidal and wind activity, fresh water input and mesoscale level hydrophysical structure of the water mass. For the coastal ecosystems, there is an intermediate situation, when during the different stages of development of phytoplanktonic communities main role belongs either to the first or a second group of factors (Larionov, 2002). This theoretical conclusion is very important in practical sense – for the complex research projects of the Arctic marine ecosystems with the purpose of forecasting possible negative consequences as a result of their exploitation. In essence, these differences define the reaction to the anthropogenic impact that causes change in the environmental parameters. Estuaries and, to a lesser degree, coastal ecosystems, experiencing a large number of ongoing local processes and well-adapted to such conditions after a long evolutionary period, accept disturbances in biotope just like an appearance of a new additional factor. They react quickly to the environmental change and the effect is basically imperceptible for the structure as a whole or is very limited in time and space.

2.4.3 Zooplankton

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In the Barents Sea ecosystem, zooplankton form 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).

Favourable 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 that are 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. rachii* is restricted to shallow waters in the southeast region. Carnivorous zooplankton such as hyperiid amphipods (*Themisto* spp.) may feed on *C. finmarchicus*; they compete with fish that consume zooplankton.

Herbivorous zooplankton in high latitude and ice-covered seas is 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). The pelagic *Calanus* species, being one of the major components of the Arctic marine ecosystem must, therefore, be adapted to an environment changing markedly on different time scales. This readily accounts for the biodiversity of the *Calanus complex* in terms of the species' different life strategies, different ecological niches and different centres of distribution.

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 north 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* has a life span of 1 to 3 years but for 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 from two to five years (Dawson, 1978, Conover and Huntly, 1991, Hirche, 1997, Falk-Petersen et al., 1999; 2008).

The interconnected current systems in the Atlantic and Arctic transports *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus* long distances and they are found distributed all over the Arctic, including the Norwegian Sea, the Barents Sea, the White Sea, the Arctic Ocean, the Greenland Sea and coastal waters bordering Siberia, East Canada and Alaska. The different species do, however, originate from different centres of distribution and are used as indicator species for the different water masses (Van Aken et al. 1991). The three *Calanus* species also have different core areas for over-wintering, the Norwegian Sea being central for *Calanus finmarchicus*, the Arctic shelf area for *C. glacialis* and the Greenland Sea and the Arctic Ocean 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 part of the Barents Sea (the Kola Peninsula coast) has lower index of maximum biomass, production possibilities of this water area are considered to be rather 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 till the Svyatoy Nos Cape constitutes 1300 mg/m^3 (July). For comparison, for the similar period in the open part of the Barents Sea this index is 2000 mg/m^3 (Kamshilov et al. 1958).

In a qualitative sense zooplankton from coastal area is characterized by presence of more than 100 species, instars and life-forms. Though, only 20 of them play an important role in formation of total community biomass and are represented by more than 100 individuals/m^3. Besides *C. finmarchicus* and euphausiids, representatives of *Metridia*, *Oithona*, *Pseudocalanus*, *Acartia*, *Temora*, *Cladocera* and larvae of acorn shells, polychaetes (Kamshilov, Zelikman, 1958; Fomin, 1978, 1985) are also referred to them.

Overall picture of zooplankton community seasonal changes is the following. The period from March till the middle of May is characterized by rapid growth of meroplanktonic forms. The most abundant of them are larvae's of barnacles (*Cirripedia*) and polychaetes (*Polychaeta*). In the given period of time quantitative rates of holoplanktonic organisms are noticeably lower than those of meroplanktonic forms. Gradual change of species complexes takes place by the end of July. Holoplanktonic organisms represented mainly by copepods *C. finmarchicus*, *Pseudocalanus elongatus*, *Oithona similis*, *Acartia* sp., *Temora longicornis*, *Microcalanus* sp. take leading positions. The end of June – August is a typical summer stage in seasonal community development. This stage is characterized by maximum of biomass during the year and by significant species diversity. Further (in the middle of August – September) gradual transition of community to climacteric state takes place. This process is expressed by reduce of total quantitative parameters of zooplankton, gradual extinction of larval forms of bottom invertebrates in pelagic zone and by growth cessation of major copepods species. Winter stage of seasonal succession demonstrates total minimum of holoplanktonic organisms biomass and absence of benthos invertebrates larvae (Fomin, 1985, Druzhkov, Fomin, 1991).

In the Barents Sea ecosystem, zooplankton form 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 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, *Themisto abyssorum* and *Themisto compressa*). 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 *hyperiids amphipods* (*Themisto* spp.) may feed on *C. finmarchicus*; 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 2.4.5 and Figure 2.4.6). In figure 2.4.5, the highest average biomass during this period was recorded in 1994 and 1995. 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 (lower panel: 0-100 m). Data from bottom-0 m and 100-0 m indicate that during the period of the ecosystem survey (August-September) the 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 relatively more abundant in 0-100m depth interval, and are more important in the upper water column during this time of the year. We observe particularly for 2008 that the biomass size-fraction 1000-2000μm (bottom-0m), which normally contains a substantially amount of the older *Calanus* stages, is significantly reduced in 2008 compared to the previous years, while the 180-1000 μm size-fraction is considerably larger than what was observed the two preceding years. This might suggest that the overwintering stock of *Calanus* in the central- and western region of the Barents Sea is significantly reduced in 2008.

The development of the krill stock of the Barents Sea (Figure 2.4.6) 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 (c.f. chapter 2.6.2.1).

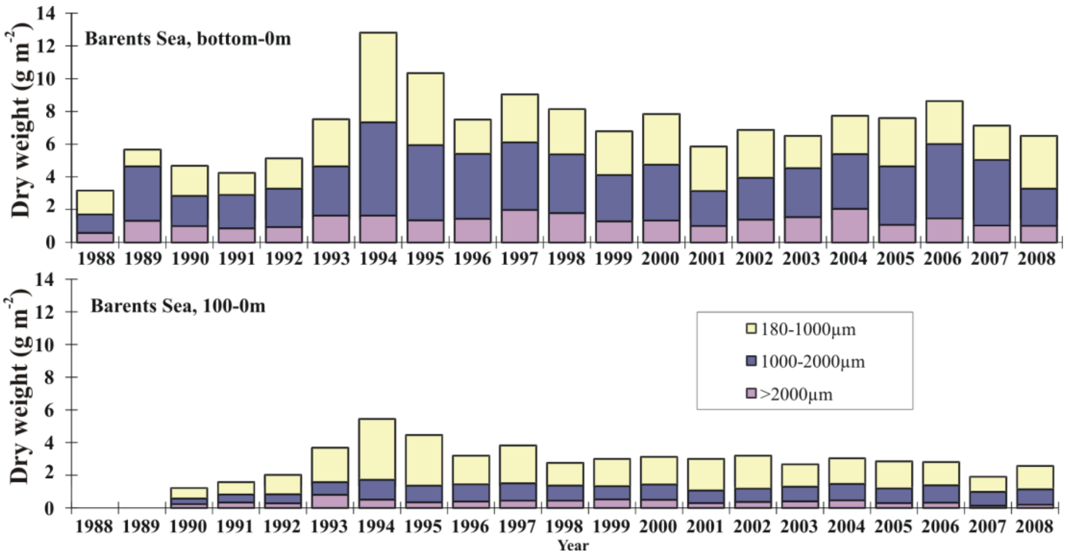

Figure 2.4.5. Long-term size composition of zooplankton biomass (WP2 net) in the water column from bottom-0 m (upper panel) and 100-0 m (lower panel) from the central-western part of the Barents Sea. Norwegian data only.

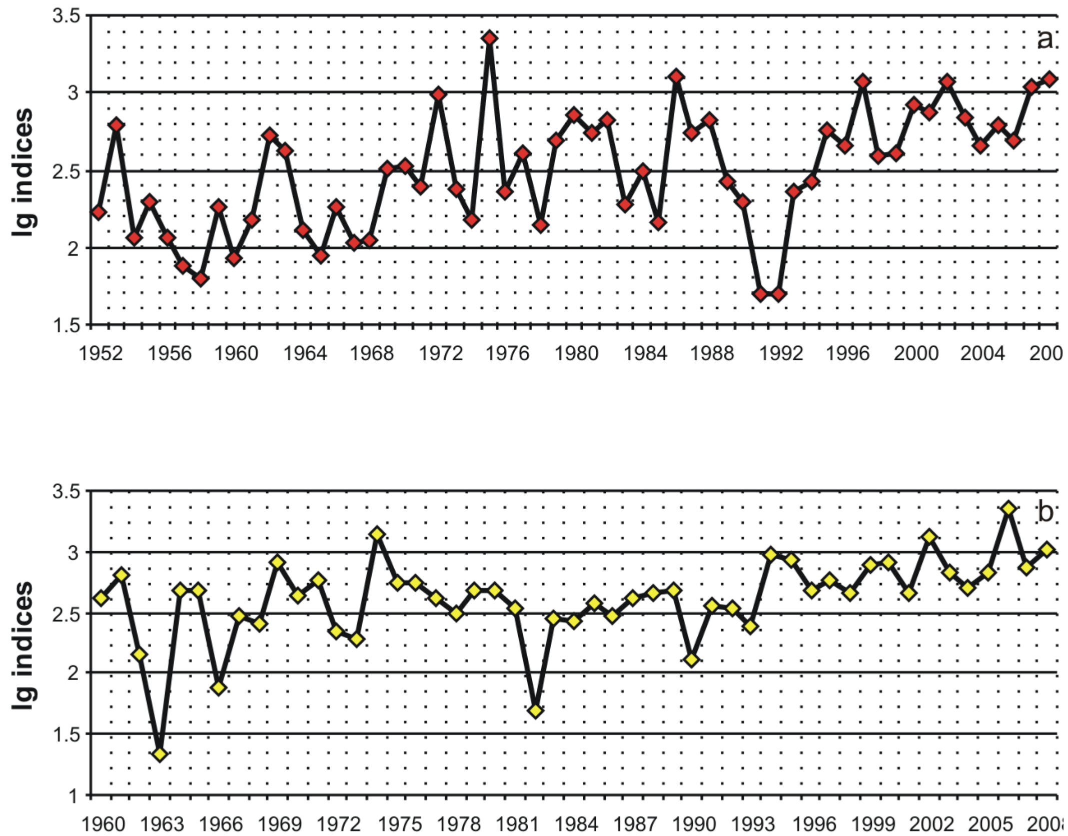

Figure 2.4.6. Variation in abundance indices of krill in southern (a) and north-western (b) regions of the Barents Sea (data from macroplankton survey conducted by PINRO).

Gelatinous zooplankton is a term often used expression 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 predominant species of "gelatinous zooplankton".

There is no available time series of data to describe these organisms in the Barents Sea. Both comb-jellies (*Ctenophora*) and "true" jellyfish are predators and many compete with plankton-eating fish, as copepods often are significant prey items for both groups. Along with increased temperatures, and changes in other components of the Barents Sea ecosystem, research interest has increased to understand how these changes effect abundance and distribution of gelatinous zooplankton and their prey. A preliminary overview of this ecosystem component on a regional scale is presented in chapter 4.3.2.3 of this report.

2.4.4 Benthos

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More than 3,050 species of invertebrates inhabit the benthos of the Barents Sea (Sirenko, 2001). Total fauna biomass, including benthic species, generally increases near the Polar Front, in shallow regions, and near the edges of banks. The richest species diversity is found on sandy silts, and silty-sand floors. Lower biomass occurs in areas with limited upwelling, low primary production, reduced vertical flux, and areas with less suitable substrata caused by heavy sedimentation (e.g. inner parts of glacial fjords).

Several large scale studies of benthos have been performed in the Barents Sea. The first study was done before the intensive bottom trawl fishing started. The studies cover periods with different climatic conditions. Together they may therefore give information on the effects of fisheries and climatic variation and change on the benthos in the Barents Sea ecosystem. A review of benthic studies in the Barents Sea is given as an electronic appendix on the Russian-Norwegian environmental web portal (http://barentsportal.com).

2.4.4.1 Distribution and fluctuations in benthic communities

There has been a decline in the total biomass of benthos from 1924-1935 to 1968-1970 (Antipova, 1975b). This happened almost throughout the Barents Sea, and has been attributed to climate change by many investigators. The mechanism behind this biomass reduction is not clear, however. Some studies suggest that it is due to a change in faunal distribution during the cold period between the 1960s and 1980s (Figure 2.4.7; Bryazgin, 1973, Antipova, 1975b, Bochkov and Kudlo, 1973), while others invoke declining biomass of resident boreal-arctic species during the 1930s-1960 warm period (Galkin, 1987; Kiyko and Pogrebov, 1997a; Kiyko and Pogrebov, 1998). Boreal-arctic species dominate the biomass of benthos in the

Barents Sea (as well as throughout the arctic shelf), and have an optimum temperature range lying within the long-term temperature mean of the region. According to this latter theory, any deviation from the long-term mean has a negative impact on boreal-arctic species reproduction, abundance, and biomass.

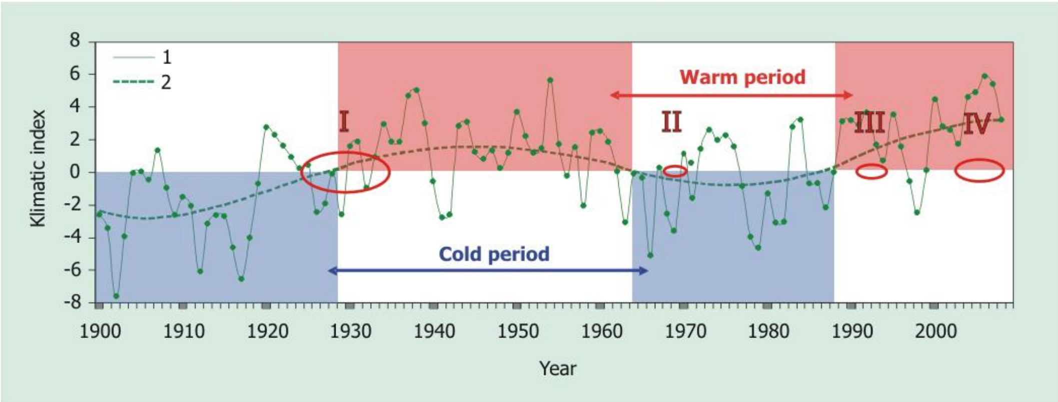

Figure 2.4.7. Interannual changes in climatic index (reflecting the cumulative variability of major indicators of a climate such as sea and air temperature and ice coverage) of the Barents Sea (1), and its quasisecular cycle (2) (Boitsov, 2006). The periods of the four main quantitative benthos surveys are shown as red circles in the chart (Source: PINRO).

The surveys done in 1924-1935 and 1991-1994 followed long-lasting cold periods with predominance of negative temperature anomalies, and the total biomass of benthos did not significantly differ between these two surveys. On the other hand it exceeded the biomass recorded after a warm period in 1968-1970 (Kiyko and Pogrebov, 1997a). Identification of these types of patterns highlight the importance of these investigations for the basic knowledge and understanding of the dynamics of the Barents Sea fauna.

2.4.4.2 The distribution of benthic abundance and biomass

The distributional pattern of benthos from different periods shows considerable variability, but demonstrates a number of more consistent features (Figure 2.4.8).

The areas with low abundance (less than 1000 individuals/ m^2) and biomass (less than 10-25 g/m^2) are usually restricted to bottom depressions such as the western deep-water areas in the Bear Island Channel and Hopen Deep, deep-water areas between Franz Josef Land and the shallow waters of the Novaya Zemlya bank and the deep-water areas in Eastern Basin. The high biomass areas (biomass hotspots) are usually located in connection with considerable rises in sea-floor topography and generally typical for the areas with hard soil and strong currents (Kiyko and Pogrebov, 1997a). The rich communities within these areas are dominated by epifauna, where the majority of species are suspension feeders. Biomass has also been found to be significantly elevated in Polar Front areas, where there is a tight coupling between primary production and the benthos (Carroll et al., 2008). Whereas the distribution of zoobenthos in the Barents Sea is related to depth, near-bottom temperature and sediment type (Dahle et. al, 1998; Denisenko, 2007), perhaps the most important factor determining the benthos biomass and distribution is the abundance and availability of food supply for benthic organisms (Zenkevich, 1961; 1970; Carmack and Wassmann, 2006;

Wassmann et al., 2006; Denisenko, 2007; Carroll et al., 2008). Quantitative characteristic of benthos along the Kola section are depended not only on temperature but also on bottom fish trawling. Denisenko (2001) showed a decrease of more than 60 % in the benthos biomass (Figure 2.4.9 left) and concluded that there was a relation between decreased benthos biomass (Figure 2.4.9 right) and high intensity of bottom fish trawling in the main fishery areas.

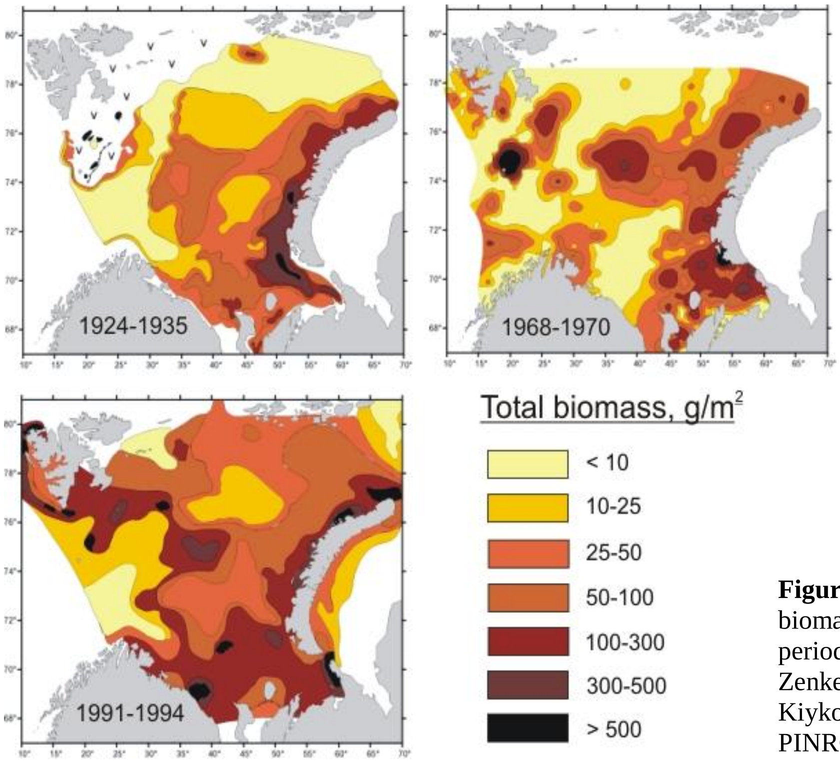

Figure 2.4.8. Distribution of the benthic biomass of the Barents Sea at different periods of researches (After Brotskaya & Zenkevich, 1939; Antipova, 1975b; Kiyko and Pogrebov, 1997a) (Source: PINRO).

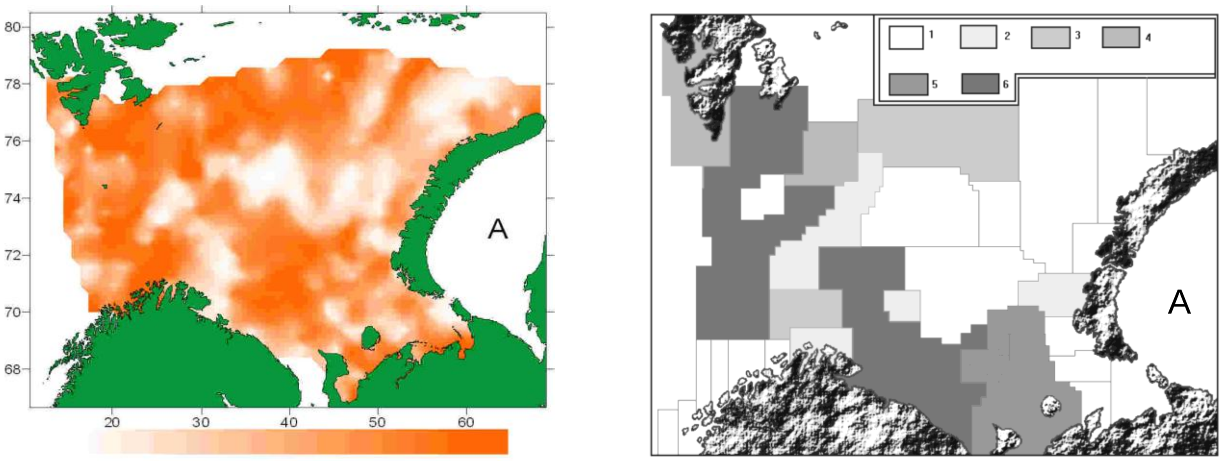

Figure 2.4.9. The gradients in biomass decrease in the Barents Sea (left) and fishing activity (right) (Denisenko, 2001).

In regions such as the Barents Sea, spatial variability in food abundance is linked to ice cover patterns. In heavily ice-influenced areas, with low annual primary production, the faunal abundance was significantly lower than that in the more productive southern waters (Cochrane et al., 2009; Figure 2.4.10).

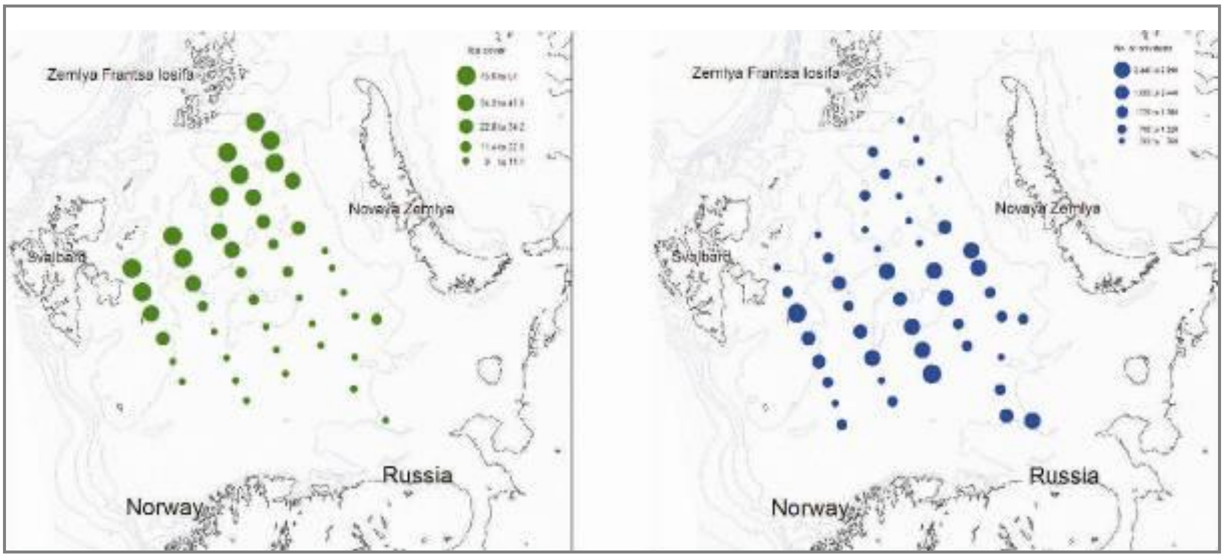

Figure 2.4.10. Schematic representation of (left) ice cover and (right) benthic faunal abundance in the Barents Sea, as sampled in 2003 (figure from Cochrane et al. 2009).

2.4.4.3 The distribution of main bottom communities

Based on the Brotskaya and Zenkevich (1939) investigation, six main bottom community areas within the open part of the Barents Sea was defined. The south western Barents Sea (I, red area in figure 2.4.11) was characterized by its high abundance of boreal species and predominance of seston-feeders in biomass, whereas the central Barents Sea (II, light blue area in figure 4), at an average depth about 200m and on sandy silt, has a rather low biomass compared to other communities in the Barents Sea.

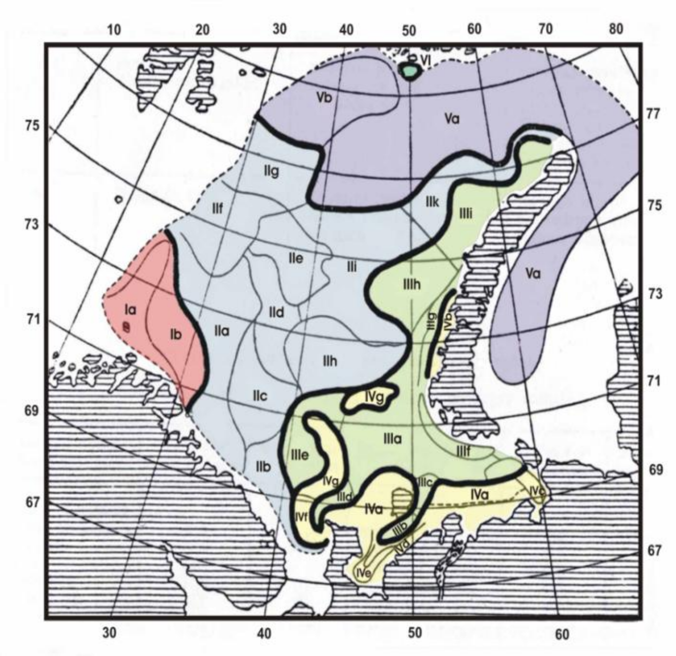

Figure 2.4.11. Distribution of bottom area complexes according to benthic surveys from 1924-1935 (after Brotskaya & Zenkevich 1939). The name and details of the area complexes are given in the text (Source: PINRO).

The species composition is very homogenous and made up primarily by the 4 dominant (in biomass) species including the polychaete *Spiochaetopterus typicus,* the bivalve *Astarte crenata*, the deposit-feeding sea star *Ctenodiscus crispatus* and the large sipunculid *Golfingia margaritacea*. In the eastern and south eastern part of the Barents Sea (III, green area in figure 2.4.11) there is a complex of communities occurring on silty and sandy sediment at depths less than 200 m. This complex is characterized by rather high benthic biomass where bivalve molluscs account for, on the average, half of the total biomass of benthos. *Astarte borealis*, *Macoma calcarea* and *Clinocardium ciliatum* are the predominant species in the communities of this complex.

The eastern and south eastern coastal communities (IV, yellow area in figure 2.4.11) occur on sandy bottoms in coastal shallow waters in the Pechora Sea, along the coast of Novaya Zemlya and Franz Josef Land. The bivalves *Astarte borealis*, *Macoma calcarea* and *Serripes groenlandicum* as well as sea squirts *Pelonaia corrugata* burrowing in the sand are predominant in biomass in this community. The biomass of coastal communities is slightly lower than in open waters of the south eastern part of the Barents Sea but still is at rather high level compared to other regions.

The Northern community (V, dark blue area in figure 2.4.11) 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* and, at some stations, bivalve mollusc *Astarte crenata* are predominant here. Finally, the Northern Barents Sea Shallow Water community (VI, white area in top of figure 2.4.11) is situated at 100 m depth at the archipelago of Franz Josef Land on sandy sediment with stones. This community is characterized by the predominance of epifauna and has a relatively high biomass.

Communities with a similar complex of dominant species were singled out in the shallow waters of Svalbard. Bivalve molluscs *Hiatella arctica* and *Astarte borealis*, barnacles of genus *Balanus* and the polychaete *Thelepus circinnatus* are predominant. All the species belong to the group of seston-feeders, and this complex is, therefore, characterized as typical for shallow waters with active hydrodynamics.

2.4.5 Shellfish

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2.4.5.1 Deep sea shrimp (*Pandalus borealis*)

The deep sea shrimp (*Pandalus borealis*, also called deepwater shrimp or Northern shrimp) are distributed in most deep waters of the Barents Sea and Spitsbergen. The densest concentrations are found in the central region of the Barents Sea, Hopen Deep, Thor Iversen Bank and near the western Murman coast at depths from 200 to 350 meters. Regular fishery for the Northern shrimp in the Barents Sea and Spitsbergen area has been conducted since 1950's. Russia has been harvesting the shrimp stock since 1976. Maximum catches were reached in the mid-1980's, as well as in 1990-1991 and 2000.

These shrimp feed mainly on detritus, but may also scavenge. They are an important food item for seals, and for many fish species, including cod, greenland halibut, and redfish.

At the international level, no quota allocation is applied to the fishery for the Northern shrimp in the Barents Sea. In economic zone of Russia the shrimp fishing are regulated by the TAC. Fishing for the shrimp in the Barents Sea and Spitsbergen area is permitted by trawls having a mesh size of not less than 35 mm with mandatory use of a selective grid (19 mm space between the bars). By-catch of juvenile cod, redfish and Greenland halibut in the shrimp fishery shall not exceed 800, 1000 and 300 individuals per 1 tonne of the shrimp, respectively.

2.4.5.2 Iceland scallop (*Chlamys islandica*)

The Iceland scallop is a slow growing species common in all shallow areas (< ca 150 m) both in the Spitsbergen area as well as along the coastal waters of Kola Peninsula and Northern Norway (Wiborg, 1962; 1968; Rubach and Sundet, 1987). It is usually associated with hard bottom substrate and most commonly in areas with strong currents (Wiborg, 1962). The scallop is a filterfeeder and is therefore highly dependent on the seasonal phytoplankton production, which also impact on its growth (Sundet and Vahl, 1981). In the Spitsbergen area,the scallop grows slowly and may become up to 30 years old (Rubach and Sundet, 1987). Unpublished data also reveal that the recruitment to the different stocks may vary significantly between periods.

In Russian EEZ, Iceland scallop are distributed in shallow waters in the south-eastern part of the Barents Sea on sandy bottom and shelly grounds at depths above 100 m. The maximum shell height is 150 mm, but considerably smaller individuals, from 70 to 110 mm, and from 50 to 60 mm off Novaya Zemlya, occur in settlements. The lifespan is 30 years and over. Iceland scallop mature by age 7-8. The number of eggs produced by females reach 500,000 (Denisenko, 1989).

2.4.5.3 Snow crab (*Chionoecetes opilio*)

The snow crab is native to waters in Alaska, the east coast of Canada and west of Greenland, and is therefore an invasive species in the Barents Sea. Throughout 2008, new recordings of this crab have been done in the western part of the Barents Sea, and it seems that this species will achieve a more northerly distribution than the red king crab.

The first finding of the snow crab *Chionoecetes opilio* (Fabricius, 1788) (*Brachyura, Majidae*) was registered in the Barents Sea in 1996 (Kuzmin et al., 1999). The snow crab has two native stocks, one in the Beering Sea and Chuckchi Sea (Alaska and Russia) and one on the northeast coast of Canada and west of Greenland. Preliminary results from DNA fingerprinting of snow crab from the Barents Sea (K. Jørstad, IMR, pers. comm.) does not match the DNA from the NW Atlantic population. It is therefore more likely that the snow crab in the Barents Sea originates from the eastern population. It cannot be ruled out that the snow crab has migrated into the Barents Sea without human assistance.

During the whole period of investigations crabs of 7-166 mm carapax length were caught. Main items in the opilio food in the southeastern Barents Sea are polychaetes, mollusks, crustaceans and echinoderms.

Snow crabs in the Barents Sea were recorded in waters from 39 to 387 m depth, predominantly on muddy or sandy and muddy grounds, at temperature from –1.6° C to 5.9° C and salinity from 34.5 to 35.1 psu in the near-bottom layer.

2.4.5.4 Red king crab (Paralithodes camtschaticus)

The red king crab (*Paralithodes camtschaticus*) was deliberately introduced to the Barents Sea at several locations during the 1960s and 1970s from the northern part of the Pacific (Olav and Ivanovo, 1978). It has continuously spread to new areas and is now distributed from the Kluge Island to east, the Goose Bank to north, and west to Lofoten and Kvænangen to west along the Norwegian coast. The expansion of the area inhabited by red-king crabs occurred during years when water temperature in Atlantic currents was higher than normal (Pinchukov and Karsakov, in press). Several studies have revealed that the crab besides being an important fishing resource, also significantly impact the bottom ecosystem in areas of high densities of crabs (Sundet and Berenboim, 2008).

In Russian waters of the Barents Sea, red-king crabs occur in areas from shallow waters to the depths below 335 m, at the temperature range from -0,8 to +8,5º C. In spring, April-May, they form spawning aggregations of individuals of both sexes within temperature range 0-2º C. In autumn, August-September, red-king crabs form separate aggregations where males aggregate in concentrations within the temperature range 4-6º C and females within 5-7º C. The individual fecundity varies from 70,000 to 700,000 eggs. The average fecundity is 250,000 eggs (Bakanev, 2003). The maximum known size is 270 mm carapax length, and weight is 7.4 kg. Red-king crabs are benthophage predators (Gerasimova and Kachanov, 1997; Manushin, 2003), but in areas with intensive fishing, they predominantly feed on fish offal (Pinchukov and Pavlov, 2002; Anisimova and Manushin, 2003). The main red-king crab predators in the Barents Sea are cod, wolffish and skates (Matyshkin, 2001).

2.4.5.5 Squids and other shellfish species with economical potential

There are three taxonomic groups of the shellfish (Mollucs, Crustaceans and Echinoderms) that have a potential commercial importance in the Barents Sea.

Squids

According to the Joint PINRO/IMR Ecosystem survey data and various literature accounts, there are 8 species of squid inhabiting the Barents Sea: *Rossia palpebrosa*, *R. moelleri* (*Sepiida*), *Cirroteuthis muelleri*, *Bathypolypus arcticus*, *Benthoctopus piscatorum* (*Octopoda*), *Gonatus fabricii*, *Todarodes sagittat* and a new species that was found for the first time in 2006 - *Todaropsis eblanae* (*Teuthida*) (Golikov at al., 2008).

The flying squid *Todarodes sagittatus* was a significant fishing 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 fabrichii is another abundant squid species in the off shore waters of the Barents and the Norwegian Sea (Bjørke, 1995). Although this species has not been a subject of stock assessment, the total biomass is probably several million tonnes. This squid is important food for several bird and cetacean species, but could probably also be seen as a potential fishing resource. The squid *Todaropsis eblanae* was first found in the Barents Sea in 2006. It is more heat-loving and appears more rarely than *Todarodes sagittatus*, and are only found in low quantites in Barents sea. But the fact of it apperance is indicating a warming of water masses in Barents sea and we can wait rich appearance of *T. sagittatus* in the future

Other shellfish species

Other groups of mollusks which can have a commercial importance is snails from genera Buccinum and Neptunea. This snails are more often near the cost line than in the open sea and might to produce high density settlements. Clams *Serripes groenlandicus*, *Ciliatocardium ciliatum* and *Arctica islandica* also might be a commercial species. This large bivalves are very numerous in the eastern parts of Barents Sea. Among the echinoderms the commercial status probably has two species: sea urchin *Strongylocentrotus droebachiensis* and large sea-cucumber *Cucumaria frondosa*. The first species has high density in the costal upper-sublittoral zone. The second species has big biomasson the hard bottom sediment in the several parts of the Barents Sea: Bear Islands, Sviatoynos bank.

2.4.6 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)

2.4.6.1 Species diversity, assemblages and zoogeography

In the Barents Sea around 100 fish species occurs regularly in survey trawl catches. The total biomass and abundance is dominated by few species; for instance, the ten most abundant fish species constituted over 90% of the total abundance of all species caught in bottom trawls on the ecosystem survey in August-September 2004-2008 (Figure 2.4.12).

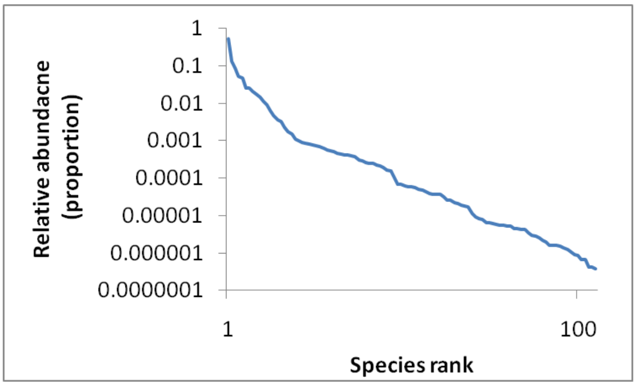

Figure 2.4.12. Relative abundance plotted against species rank (Whittaker plot) for fish species in the bottom trawl catches in the ecosystem survey 2004-2008.

More than 200 species from 70 families have been registered in the Barents Sea. The most important families are: eelpouts (*Zoarcidae*), codfishes (*Gadidae*), sculpins (*Cottidae*), snailfishes (*Liparidae*), skates (*Rajidae*), flatfishes (*Pleuronectidae*) and rocklings, lings and tusk (*Lotidae*). These families account for over 80 % of the species regularly occurring in the Barents Sea.

The different fish species are not evenly distributed in the Barents Sea, but have highest abundance in the areas where the environmental conditions suit their preferences. The different water masses, i.e. coastal water, Atlantic water, Arctic water and the frontal zones between these water masses, together with bottom type and depth, are important factors determining the distribution and abundance of the fish species. For pelagic species the distribution and abundance of zooplankton is also very important. Species with the same environmental preferences will co-occur in limited geographical areas and form fish assemblages, with distinctive species compositions .Figure 2.4.13 shows how different demersal fish assemblages were distributed in the Barents Sea in August-September 2007.

There is a distinct species grouping north of the Polar Front in Arctic water, two frontal groups (one deep and one shallow) and one grouping in the southwest and along the shelf associated with warmer Atlantic water. There are also several coastal groups, along Spitsbergen, the Norwegian coast, the Murman coast and the coast of Novaya Zemlya. Each of these groups are characterised by their species composition and by the relative abundances of the species present.

Andriyashev and Chernova (1995) classified fish 166 species recorded in the Barents Sea into seven zoogeographical groups (see Table 2.4.1 for definitions). Out of these107 are regularly occurring (Figure 2.4.14).

All of the species classified as Arcto-boreal and Mainly boreal are regularly occurring. The Arctic species have their southern distribution border in the Barents Sea north of the polar front. Some of the Arctic species are deep water species belonging to the polar basin, and 80 % of the Arctic species recorded in the Barents Sea are regularly occurring. The species classified as Boreal and South Boreal have their northern distribution border in the Barents Sea, and 50 % of them are regularly occurring. Less than 10% of the Widely Distributed species are regularly occurring, and can be considered as vagrants. Due to the recent increase in temperature in the Barents Sea, the increased inflow of Atlantic water and the range expansion of many fish species found in southern areas, new recordings of Boreal, South Boreal and Widely Distributed fish species are to be expected in the Barents Sea.

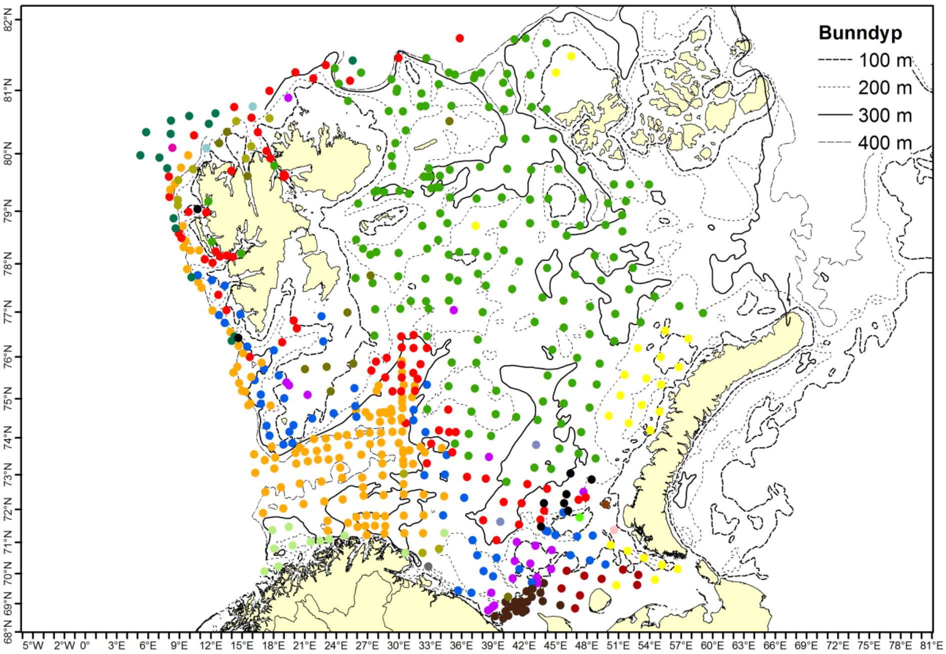

Figure 2.4.13. Bottom trawl stations grouped by demersal fish species composition. Abundance data from experimental bottom trawl catches during the ecosystem survey in 2007. Non-representative samples were excluded, leaving a total of 581 bottom trawl stations. Fifteen pelagic species were excluded from the analysis, leaving 77 species or species groups.

The cluster analysis was done using the software PRIMER, applying Bray Curtis similarity and a Cut off level for low contributions of 90.00%. The abundance data (number of individuals per haul) was standardised into numbers per 3 nautical miles towed (i.e. comparable with 1 hour trawling) and log transformed. The three most abundant species (cod, haddock and long rough dab) was excluded from the analysis. These species are abundant and ubiquitous in the entire survey area and analyses incorporating these species showed a pattern reflecting the abundance variation of these species while not revealing any information on the overall species composition and assemblage structure and distribution.

Table 2.4.1. 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 distribution	Species common not only in the boreal and subtropical zone, but also in the warm waters

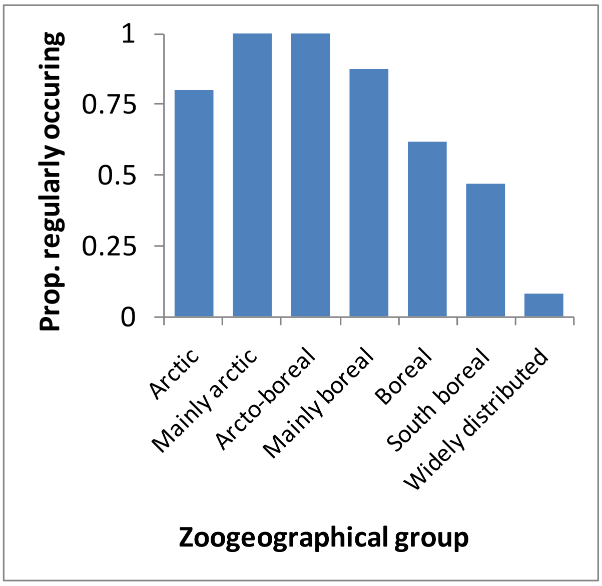

Figure 2.4.14.. Proportion of fish species recorded in the Barents Sea (n=166) from Andriyashev and Chernova (1995) that are regularly occurring (n=107) classified by zoogeographical groups.

2.4.6.2 Main fish species – stock size and fluctuations

Principal demersal stocks of economic importance are cod, haddock, redfish (mainly deep-sea redfish, *Sebastes mentella*), Greenland halibut, long rough dab, wolffish and European plaice (*Pleuronectes platessa*). Analytical assessments have not been conducted on long rough dab, wolffish, and plaice. The main pelagic stocks are capelin, polar cod and immature Norwegian Spring-Spawning herring. From 2000-2007 there was in addition a high abundance of blue whiting in the western Barents Sea. All these species have shown significant variations in abundance (Figure 2.4.15 and Figure 2.4.16. These variations are due to a combination of fishing pressure and environmental variability. Until the 1970s the deep-sea redfish was an abundant stock in the Barents Sea. Due to heavy overfishing the stock declined strongly during the 1980s, and has since remained at low levels.

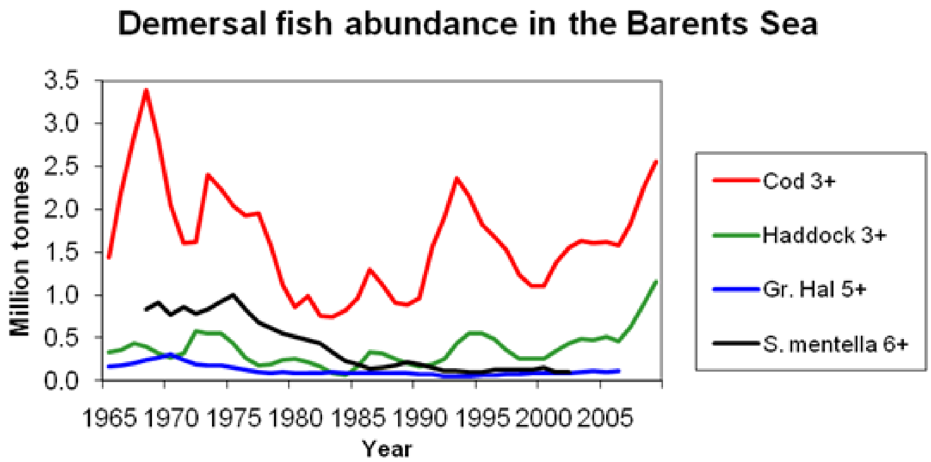

Figure 2.4.15. Biomass of demersal fish species in the Barents Sea. Data are taken from; cod: VPA estimates, age 3+ (ICES, 2009); haddock: VPA estimates, age 3+ (ICES, 2009); Greenland halibut: VPA estimates, age 5+ (ICES, 2007); Sebastes mentella: VPA estimates, age 6+ (ICES, 1995 for the years 1968-1990; ICES, 2003 for the years 1991-2002).

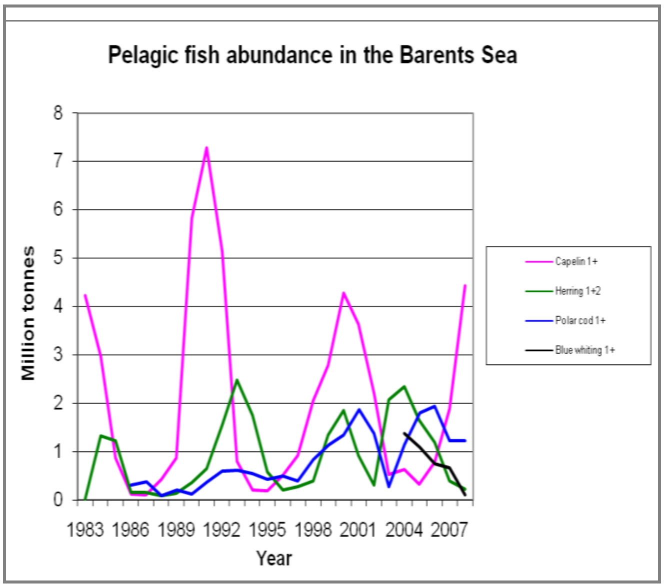

Figure 2.4.16. Biomass of pelagic fish species in the Barents Sea. Data are taken from; capelin: Acoustic estimates in September-October, age 1+ (ICES AFWG 2009;Anon. 2008, herring: VPA estimates of age 1 and 2 herring (ICES WGWIDE 2008) using standard weights at age (9 g for age 1 and 20g for age 2); polar cod: Acoustic estimates in September-October, age 1+ (Anon., 2008); blue whiting: Acoustic estimates in September-October, age 1+ (Anon., 2008).

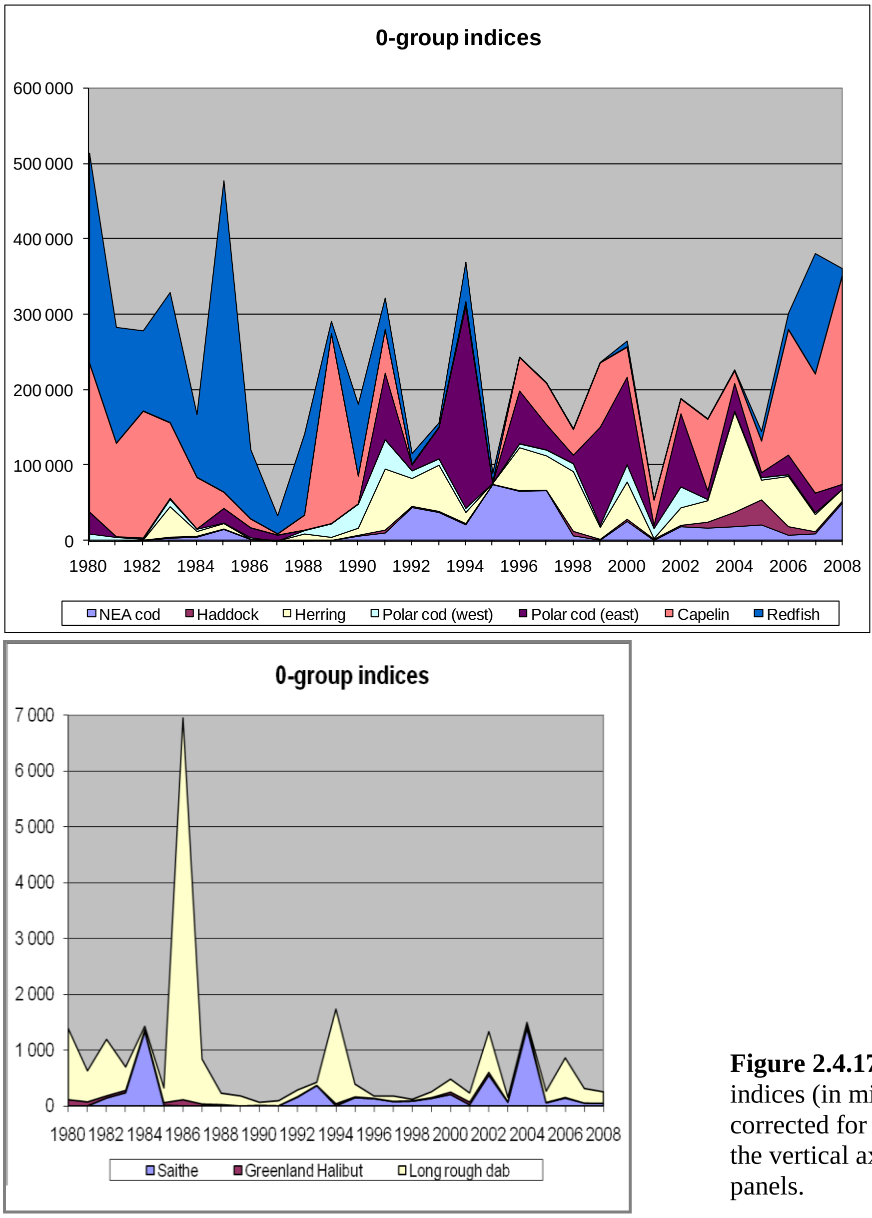

Figure 2.4.17. 0 age-group abundance indices (in millions of individuals) not corrected for catching efficiency. Note that the vertical axes differ between the two panels.

Recruitment of Barents Sea fish species has significant interannual variability (Figure 2.4.17). Factors contributing to this variability include: spawning stock biomass;, climate conditions; food availability; and abundance and distribution of predators. Variation in recruitment of some species, including cod and herring, has been associated with changing influx of Atlantic waters into the Barents Sea.

Cod (Gadus morhua)

Adult cod have an annual spawning migration from the Barents Sea to the western coast of Norway. Spawning largely occurs in the Lofoten area during March-April. Cod larvae are advected with the Norwegian coastal current and 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 in 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).

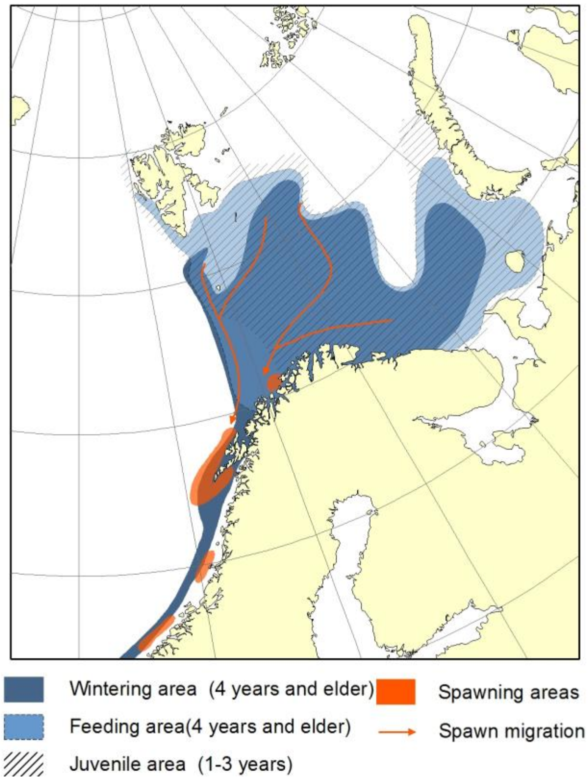

Figure 2.4.18. Distribution area for Northeast Arctic cod..

Along the Norwegian coast, coastal cod is fished together with Northeast Arctic cod. However, there is no separate TAC for coastal cod; the Norwegian cod TAC includes both coastal cod and Northeast Arctic cod. The coastal cod is at a low level. The catches are separated to type of cod by the structure of the otoliths taken from samples of the commercial fishery.

Haddock (Melanogrammus aeglefinus)
Haddock is an important demersal gadoid species that undertakes extensive migrations to and from its spawning grounds in the Barents Sea (ICES c2007-2008) (Figure 2.4.19). Variation in recruitment of haddock has been associated with changes in the influx of Atlantic waters to the Barents Sea.

Water temperature at the first and second years of the haddock life cycle is an indicator of year class strength; during this period of its life cycle if mean annual water temperature in the bottom layer does not exceed 3.8°C the probability of having a strong year class is low, even if other remaining factors are favourable. 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, molluscs, 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 fish species, i.e. young herring, or consume euphausiids and other benthic organisms (Zatsepin 1939; Tseeb 1964). Haddock stock size large natural variation, and is believed to be density-dependent. 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 in the diet of marine mammals increases.

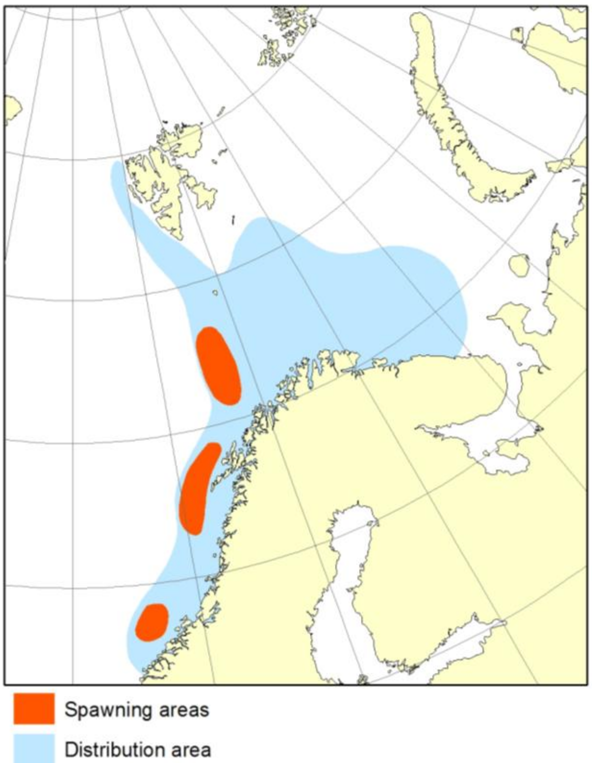

Figure 2.4.19. Distribution area for Northeast Arctic haddock.

Redfish (Sebastes mentella and Sebastes marinus)

Deep-sea redfish (*S. mentella*) and golden redfish (*S. marinus*) have traditionally been important fish 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 take larger prey, including other fish species (Dolgov and Drevetnyak, 1993). Until 1990, huge amounts of redfish postlarvae filled the pelagic Barents Sea every summer and autumn. These 0 age-group redfish consumed plankton, and were consumed other by other larger fish species. It is unknown if the niche once filled by redfish has been taken over by other plankton feeders. Since redfish are viviparous and give birth to live larvae, a strong relationship is believed between age composition of the spawning stock and levels of recruitment. Low abundance of redfish larvae and juveniles in the Barents Sea 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 stock production.

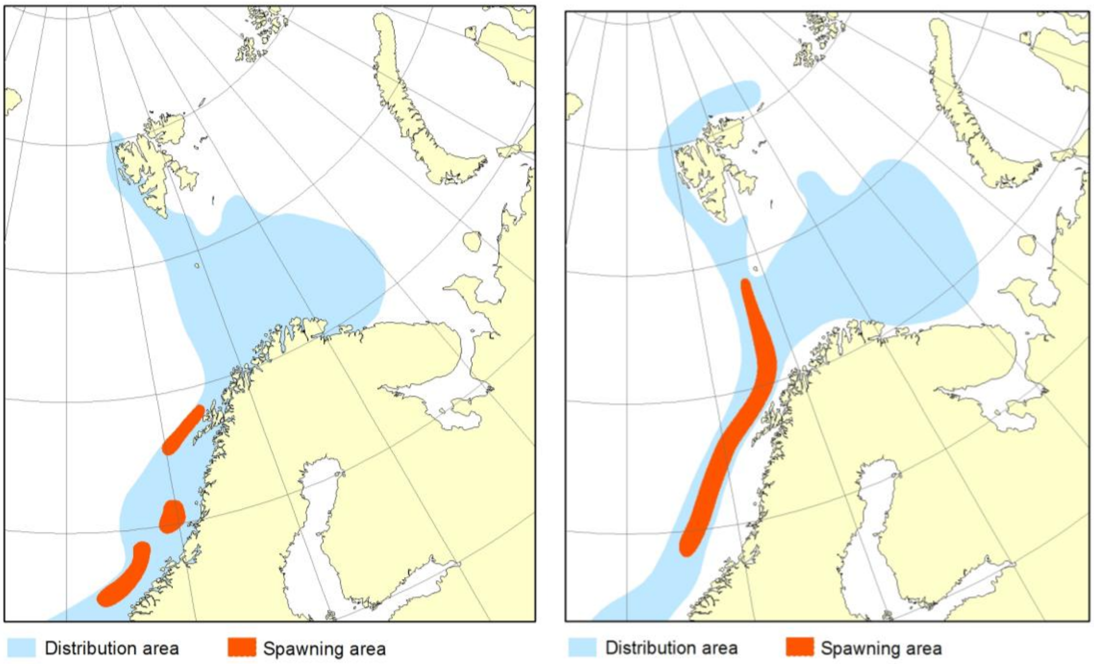

Figure 2.4.20. Distribution area for deep Sea redfish (lower) and golden redfish (upper) in the Barents Sea region.

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 its most important adult area; it is also found in the deeper parts of the Barents Sea (Figure 2.4.21). Investigations during the period 1968-1990 (Nizovtsev, 1975; Shvagzhdis, 1990; Michalsen and Nedreaas, 1998; Dolgov, 2000) indicated that cephalopods (squids, octopuses) and fish (mainly capelin and herring) predominated in Greenland halibut stomachs. With increasing predator length, ontogenetic shifts in prey preference were clear: decreasing proportion of small prey (shrimps and small capelin); and increasing proportion of larger fish. The largest Greenland halibut (length more than 65-70 cm) sampled primarily had cod and haddock in its stomach.

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; it, thus, serves as a major transporter of biomass from the northern Barents Sea to the south (Hamre, 1994). During summer capelin migrate northwards as the ice retreats; consequently, they have continuous access to new zooplankton in the productive zone recently uncovered due to melting ice. They often have reached 78-80˚N by September-October, before beginning their southward migration to spawn on northern coasts of Norway and Russia. During spawning migration capelin are preyed upon extensively by cod. Capelin are also important prey for piscivorous fish species, several marine mammals, and birds (Dolgov, 2002).

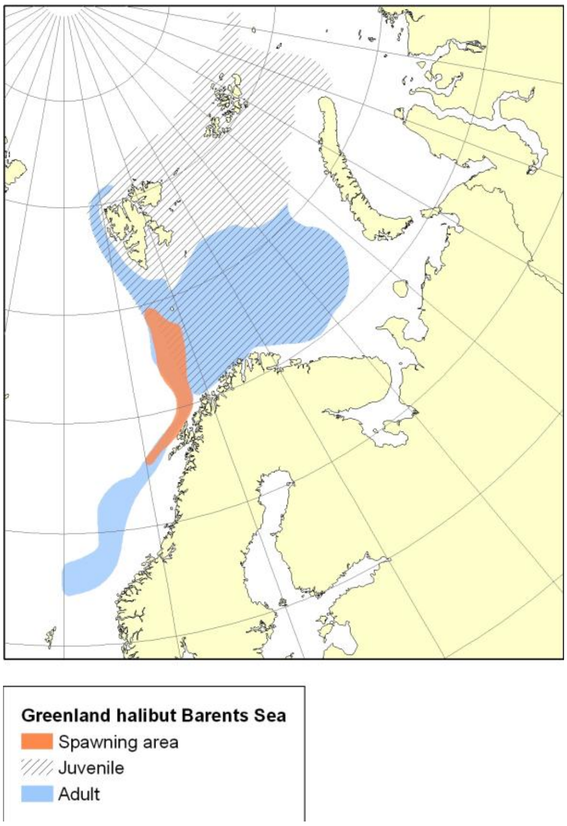

Figure 2.4.21. Distribution area for Northeast Arctic Greenland halibut.

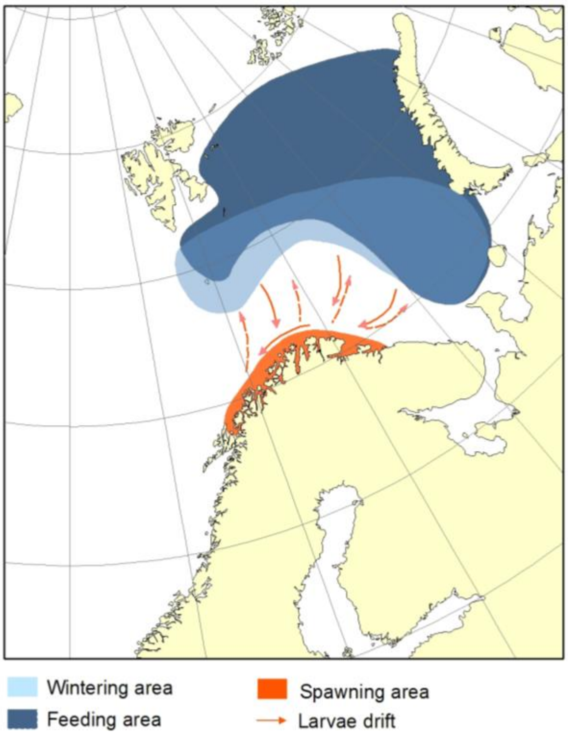

Figure 2.4.22. Distribution area for Barents Sea capelin.

Herring (Clupea harengus)

The herring spawns along the western coast of Norway; the larvae are transported northwards to coastal areas of the southern Barents Sea, and into some Norwegian fjords. Juveniles are distributed in the southern parts of the Barents Sea, which they use as a nursery area for approximately three years before they migrate west and south along the Norwegian coast join the adult stock. An abundance of young herring in this area has an effect on recruitment of capelin; there is evidence that when rich year classes of herring enter the Barents Sea, the following year's recruitment to the capelin stock is usually poor, and the subsequent year's capelin stock collapses (Gjøsæter and Bogstad, 1998). This happened after the strong 1983, 1991-1992 and 1998-1999 year classes of herring entered the Barents Sea. In recent years, the capelin stock has recovered, although the biomass of young herring in the area has been at an intermediate level.

In the south-eastern Barents Sea, both Norwegian spring-spawning herring and local herring stocks (Cheshko-Pecherskaja herring) are found. They are separated by counting the number of vertebrae. In the acoustic estimates of young herring in this area, the proportion of each stock is determined separately for each WMO square (1° latitude x 2° longitude).

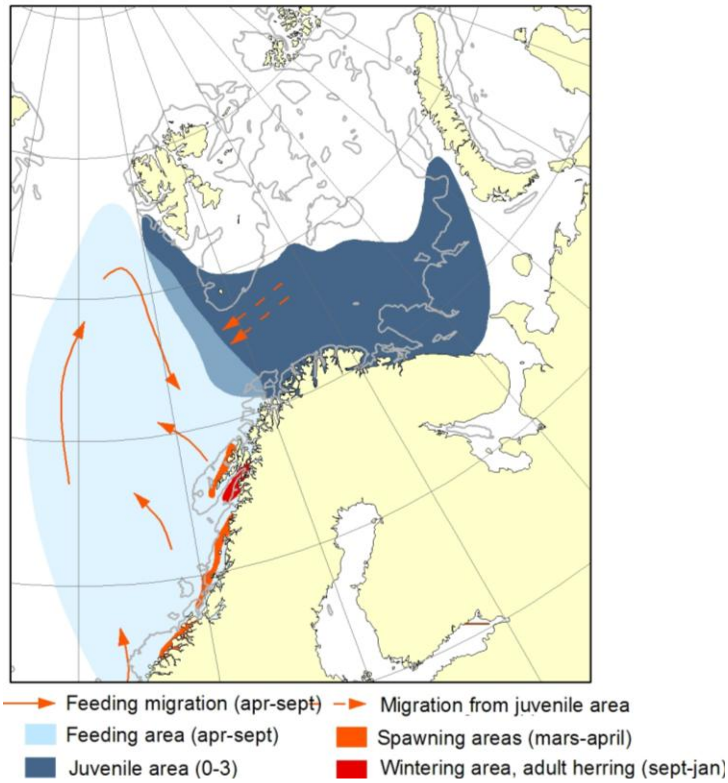

Figure 2.4.23. Distribution area for Norwegian spring spawning herring.

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 corner; and to the east of Spitsbergen. 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. There is at present little fishing on this stock.

Blue Whiting (Micromestisius poutassou)

The blue whiting is mainly distributed in the Norwegian Sea, the northeast Atlantic (Figure 2.4.25). 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; subsequent blue whiting abundance has been significant until 2007. During its early life history (until age 5), this species is primarily a plankton feeder; its food preferences become more piscivorous during its life cycle (Belikov et al., 2004). Historically, capelin, polar cod and young herring have been predominant plankton-feeding fish species. The general distribution pattern for these four species has only minimal overlap: blue whiting in the west; herring in the south; polar cod in the east (some overlap in the Spitsbergen region); and capelin in the north. In the south-western region, blue whiting and herring may overlap in their area 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 of water column — indicates low interspecific competition in feeding on the local zooplankton.

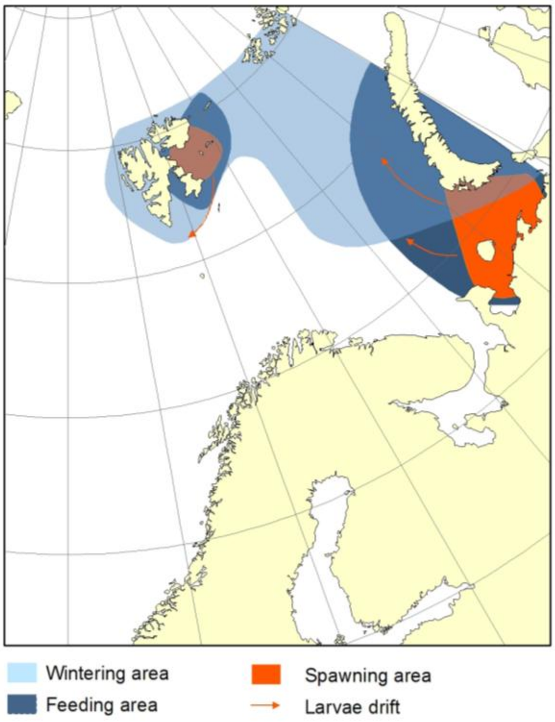

Figure 2.4.24. Distribution area for polar cod.

Figure 2.4.25. Distribution area for blue whiting.

Saithe (Pollachius virens)

Saithe is a boreal species found in north Atlantic waters (Figure 2.4.26). In the north-eastern Atlantic saithe is separated into six stocks: 1) west of Ireland; 2) west of Scotland; 3) at Iceland; 4) at the Faeroe Islands; 5) in the North Sea; and 6) northeast Arctic saithe — 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.

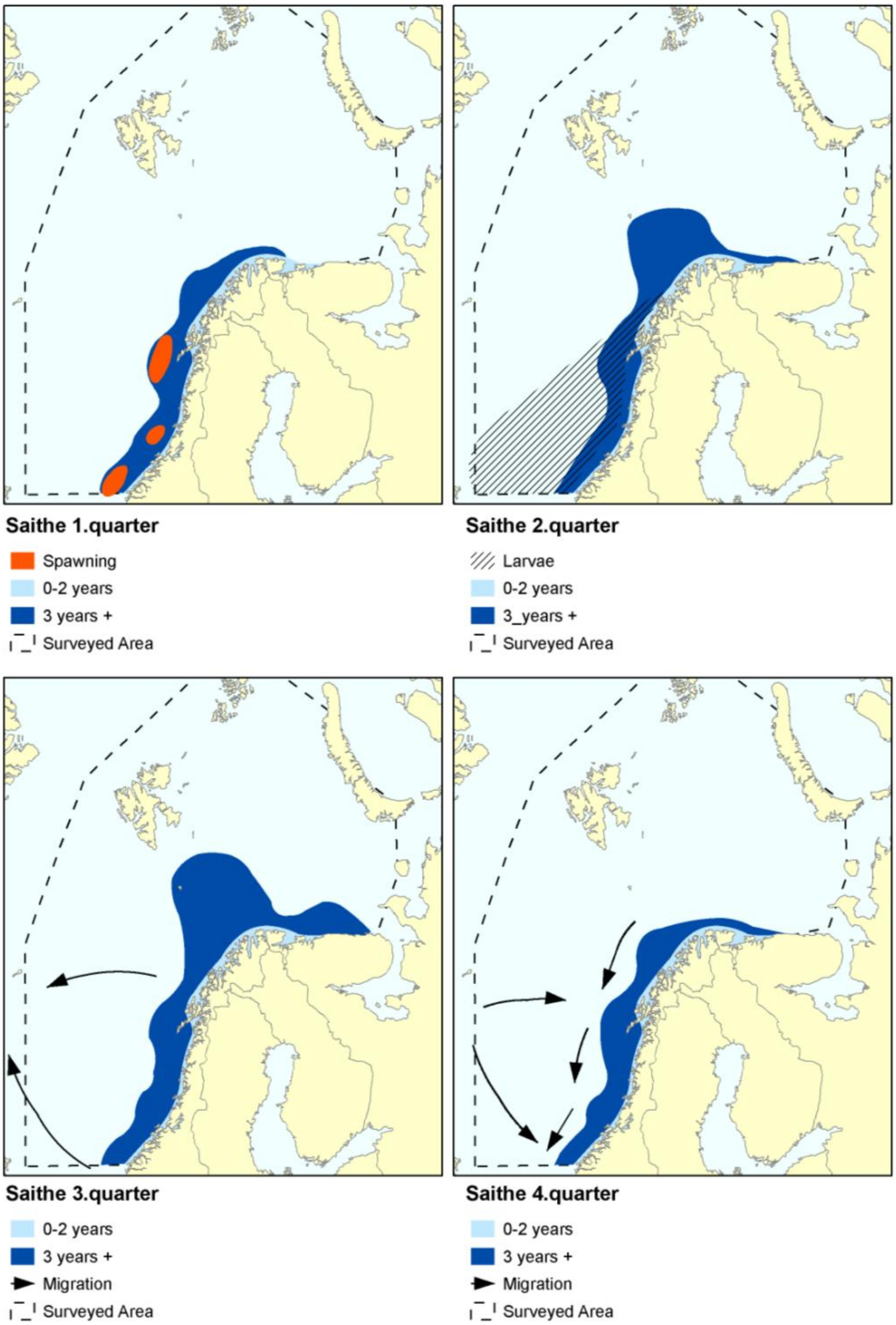

Figure 2.4.26. Distribution of saithe larvae, juveniles, age 3+, spawning areas and main migration patterns by quarter.

Tagging experiments indicate that saithe make 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 Faeroe Islands. Saithe are both pelagic and demersal, found at depths from 0-300 m. They often occur in dense concentrations, e.g. in the pelagic zone where currents concentrate prey items. Predominant prey items for young saithe are *Calanus*, 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; the peak is during February at depths from 150-200 m and temperatures from 6–10 ˚C. They take regular annual spawning migrations from the northern coast of Norway to spawning areas off the western coast of Norway; they sometimes migrate to northern regions of the North Sea, but to a lesser extent. Principal spawning areas are: Lofoten, Haltenbanken, and banks outside Møre and Romsdal region in the Sunnmøre archipelago. Eggs and larvae drift northward with the currents, 0 age-group saithe use as nursery grounds shore areas extending on the western coast of Norway to south-eastern regions of the Barents Sea; they migrate to coastal banks as 2–4 year olds.

Other species
Three species of *Anarhichas* (common wolffish- *Anarhichas lupus*, spotted wolffish- *A. minor* and northern wolffish- *A. denticulatus*) inhabit the Barents Sea and adjacent waters. Wolffish are large (up to 180 cm), long-lived (up to 25 years), and demersal. These life-history traits make them 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 a commercial species, detailed information on the life history and ecology is lacking, and physical processes that influence the dynamics of this species are not well understood. For 2004-2005, the swept area abundance of long rough dab was estimated at 300,000 tons based on the ecosystem survey. This is probably a minimum estimate of stock abundance.

2.4.7 Marine mammals

K.M. Kovacs (NPI), S.E. Belikov (VNIIPriroda), T. Haug (IMR), N.N. Lukin (PINRO), M. Skern-Mauritzen (IMR), V.N. Svetochev (MMBI) and, V.N. Zabavnikov (PINRO)

Polar bears, seven pinniped species and five cetacean species reside full-time in the Barents Sea region. Eight additional whale species are regular seasonal migrants that come into the Barents Sea to take advantage of the seasonal, summer-time peak in productivity as the ice retreats northward. Three additional dolphin species are occasionally observed in the southern Barents Sea (Table 2.2) and sei whales (*Balaenoptera borealis*) have been observed north of 79° off the west coast of Spitsbergen, but are still considered rare north of the Norwegian Sea, despite increasing numbers of sightings in Svalbard and elsewhere in the region.

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 variance in life-history strategies and ecology (Kovacs et al., 2009). Life spans range from 20-30 years for the small cetaceans and most seals, up to over 200 years in the case of the bowhead whale; several of the resident cetaceans live to be over 100. Concomittantly, age at maturity ranges from about 4 years of age up to over 25 years of age and production rates vary from the standard one-young-per-year for most species, to one young every 4 or 5 years in the case of some foraging specialist such as walruses and bowhead whales. Only the polar bear has more than one cub per reproductive episode, all other marine mammals within the Barents Region give birth to single offspring.

Most species feed at high trophic levels, with the polar bear and killer whale being apex predators; although some of the largest baleen whales, such as blue whales and bowhead whales feed low in the food web, at the plankton level, specialising on krill and copepods, respectively. The total biomass of these mammals implies that they play an important role in the structure and functioning of the 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). However, examples of the impacts of extreme lack of prey, such as the effects of the capelin crashes in the Barents Sea in the 1980s and 1990s illustrate that these top predators do not escape “bottom-up” control completely (Haug et al., 1991; Nilssen et al., 1998); they can be impacted by overexploitation by fisheries or environmental cycles that causes collapses of their prey.

Minke whales and the harp seal are currently commercially exploited. Ringed seal and bearded seals are also routinely harvested, at lower levels both in Russia and in Norway. Most of these harvests are based on annually set quotas. Additionally, there is a quota set for harvesting white whales in the Russian Barents Region; 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 additionally restricted 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 of the other marine mammals are protected throughout the Barents Sea, both in Norwegian and Russian territories.

The great abundance and diversity of marine mammals in the Barents Sea area was what attracted the attention of the earliest European explorers to the region. Massive harvests that 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 concentrated on the fat, slow “right whale” family (including the bowhead in the High Arctic). Walruses, seals and polar bears were initially taken largely as a by-catch of northern whaling, but these animals have also been the subjects of significant commercial harvests over time in the Barents Sea and adjacent areas. West Ice harp seals and hooded seals have been the subject of centuries of commercial harvest; though due to precipitous declines in the latter species since WWII, hooded seals are now Red Listed both in Norway and internationally and the West Ice quota (Norwegian and Russian hunting area) is set at zero (ICES, 2008; Salberg et al., 2008). Despite what is, in hindsight, a repeated, tragic history of over-exploitation, the marine mammal community of the Barents Sea region is still rich in species, and some populations, particularly among the pinnipeds, are very abundant (Tables 2.4.2, Figure 2.4.27).

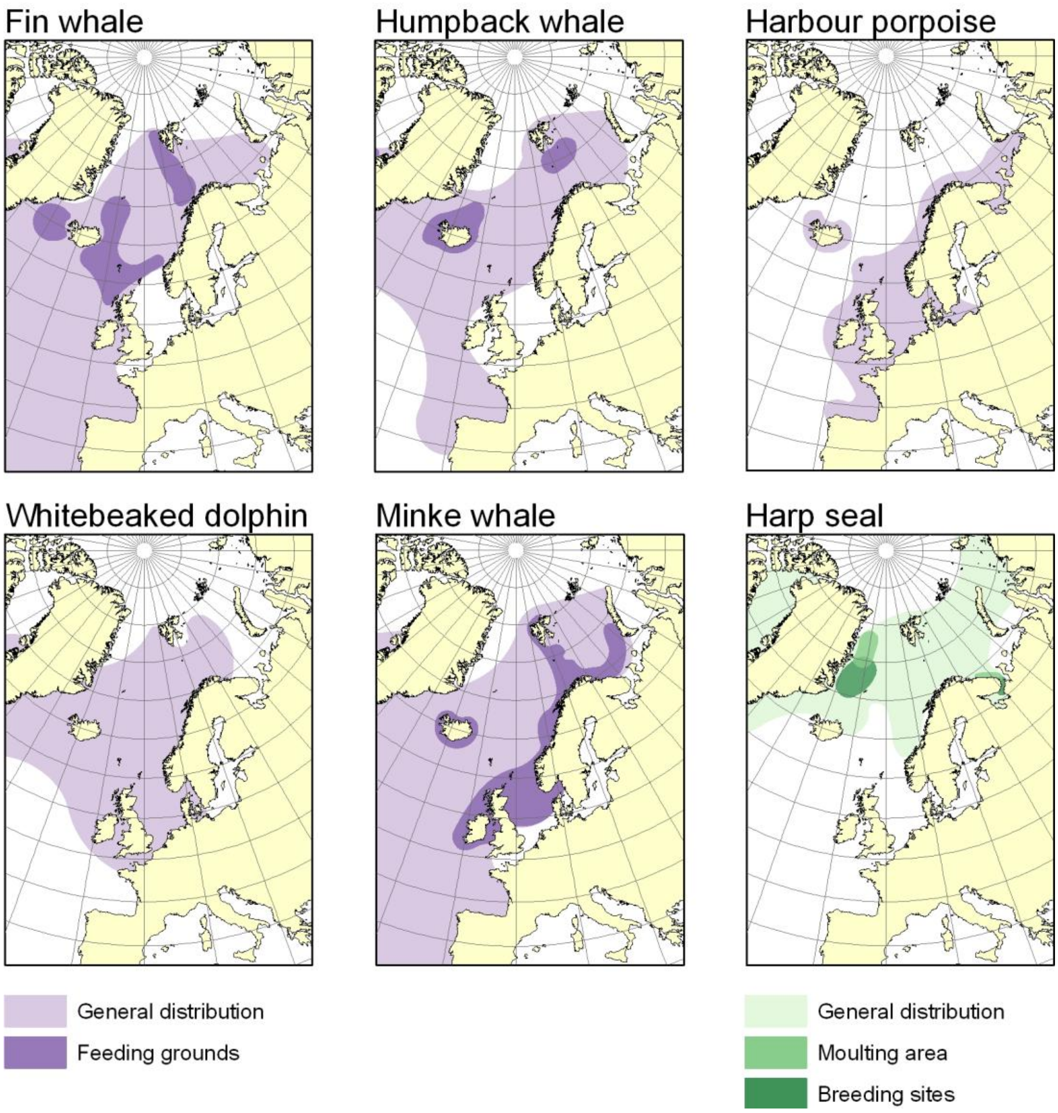

Figure 2.4.27. General distribution areas and feeding grounds for selected whale species. General distribution, moulting areas and breeding sites for harp seals in the North Atlantic.

Table 2.4.2. 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 resident	2,650 (95% CI: 1,900–3,600)[1]	E
Walrus *Odobenus rosmarus*	Year-round resident	5,000 (Sval. – 2,629 - 95% CI: 2318– 2998)[2]	?
Ringed seal *Pusa hispida*	Year-round resident	100,000 (Sval. partial - 7,585 - 95% CI: 6,332–9,085)[3] 20,000 White Sea[3b]	??
Bearded seal *Erignathus barbatus*	Year-round resident	~10,000	???
Harp seal *Pagophilus groenlandicus*	Year-round resident*	861,728 (Barents Sea stock, only point estimate available)[4] 756,000 (95% CI: 550,000-960,000; Greenland Sea stock)[4]	E
Hooded seal *Cystophora cristata*	Year-round resident*	82,400 (95% CI: 65,200-99,600)[4]	E
Grey seal *Halichoerus grypus*	Year-round resident	4,500[5]	
Harbour seal *Phoca vitulina*	Year-round resident	2,500 (Sval. ~1000[6], Troms and Finmark 1000[7], 400-500 Murman Coast [8])	?
Blue whale *Balaenoptera musculus*	Seasonal migrant	NE Atlantic 979 (95% CI: 137-2542)[9]	E
Fin whale *Balaenoptera physalus*	Seasonal migrant	NE Atlantic 6,409 (95% CI: 4,356-9,431)[10] (c. 1,800 in Barents Sea proper and Spitsbergen Shelf)	E
Humpback whale *Megaptera novaeangliae*	Seasonal migrant	NE Atlantic 1,450 (95% CI: 898-2,341)[10]	E
Bowhead whale *Balaena mysticetus*	Year-round resident	10-100[11]	???
Minke whale *Balaenoptera acutorostrata*	Seasonal migrant	NE Atlantic 80 487[12] Barents Sea and coast 62,592	E
White whale (beluga) *Delphinapterus leucas*	Year-round resident	10,000	???
Narwhal *Monodon monoceros*	Year-round resident	1,000	???
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
White-beaked dolphin *Lagenorhynchus albirostris*	Year-round resident	60,000-70,000[15]	??
Common dolphin *Delphinus delphis*	Summer vagrant	-	-

Table 2.4.2 Cont.

Common Name *Genus species*	Residency status	Abundance	Uncertainty* level
Bottlenose dolphin *Tursiops truncatus*	Summer vagrant	-	-
White-sided dolphin *Lagenorhynchus acutus*	Summer vagrant	-	-
Harbour porpoise *Phocoena phocoena*	Year-round resident	11,000[16]	?

*There is a broad range of uncertainty levels in the assessments of abudance of marine mammal population in the Barents Region: some populations have been assessed recently and completely (E); while many estimates represent partial estimates by region that have been extrapolated to the whole Barents Sea in the extreme there is little or no available abundance data – so the numbers presented represent educated guesses based on sighting records or other non-quantiative estimators.

**Harp and hooded seals "step-out" of the Barents Sea for breeding, and in the case of the latter species, some post-breeding, pre-moulting foraging expeditions as well – but some of the population(s) spend much of the year in the Barents Region.

Sources: [1]Aars et al. (2009), [2]Lydersen et al. (2008), [3a]Krafft et al. (2006), [3b]Lukin et al., (2006); [4]ICES (2008), [5]Nilssen and Haug (2007), Ziryanov and Mishin (2007) [6]Lydersen and Kovacs (2001), [7]Nilssen et al. (2009), [8]Zyryanov (2000), [9]Pike et al. (2009), [10]Øien (2008), [11]Christensen et al. (1992a), [12]Skaug et al. (2004), [13]Foote et al. (2007), [14]Klepikovskiy and Shestopal (2006); [15]Øien (1993), [16]Bjørge and Øien (1995).

2.4.8 Seabirds

H. Strøm (NPI), M. V. Gavrilo (AARI), J. V. Krasnov (MMBI) and G. H. Systad (NINA)

Seabirds spend most of the year at sea, visit land only to breed and find all their food in the marine environment (Schreiber and Burger, 2002). Seabirds are characterized by long life (10-40 years), deferred maturity (breeding age delayed up to five years of age, small clutch size (in many cases one egg) and extended chick rearing periods (sometimes up to several months; Schreiber and Burger, 2002). This life history implies that seabird populations are more vulnerable to factors that affect adult survival than factors that affect breeding success or the survival of immature (Gaston, 2004). Many seabirds are specialised top predators and changes in their behaviour or population dynamics may therefore reflect changes in the lower trophic levels at an early stage. This position makes them suitable as indicators of changes in the marine environment (e.g. Cairns, 1992; Furness and Camphuysen, 1997; Tasker and Furness, 2003).

Seabirds considered in this report represents five principal systematic groups including *Gaviiformes* (divers), *Procellariiformes* (petrels), *Pelicaniformes* (cormorants and gannets), *Anseriformes* (seaducks), and *Charadriiforms* (skuas, gulls, terns, phalaropes, and alcids). A total of 33 species breed regularly in the Barents Sea Region (Table 2.4.3, Figure 2.4.28). Based on their foraging habitats (coastal vs. pelagic), their behaviour (surface feeding vs. diving) and principal diet (fish, zooplankton or benthos) the species can be divided into five ecological groups (Anker-Nilssen, 1994). 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 of the species breeding in the region are to some extent migratory, utilizing the high productivity during summer. Although many populations leave the region during autumn and winter, they are replaced by other populations from breeding areas further to the east, wintering in the Barents Sea (e.g. Steller's eider *Polysticta stelleri* and king eider *Somateria spectabilis*, Figure 2.4.29*)*.

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). About 20-25 million seabirds harvest approximately 1.2 million tonnes of biomass annually from the area (Barrett et al. 2002). The most numerous species are the Brünnich's guillemot (1.25 mill. pairs), little auk (>1.000 000 pairs), Atlantic puffin (910 000 pairs) and black-legged kittiwake (680 000 pairs). Common too are Northern fulmar (500 000-1 000 000), 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). In total, more than 5 million pairs of seabirds breed in the region. 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 2.4.3). However, precise status estimates of different seabird species in the Barents Sea region are complicated due to lack of updated information from the eastern Barents Sea, especially Novaya Zemlya and Franz Josef Land.

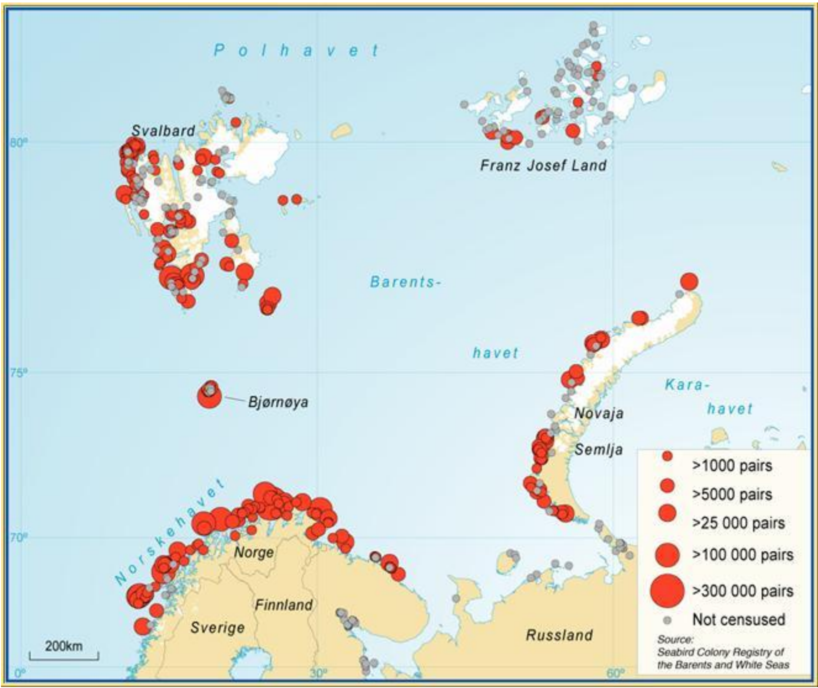

Figure 2.4.28. Seabird colonies in the Barents Sea Region. Source: The Seabird Colony Registry of the Barents and White Seas and NINA.

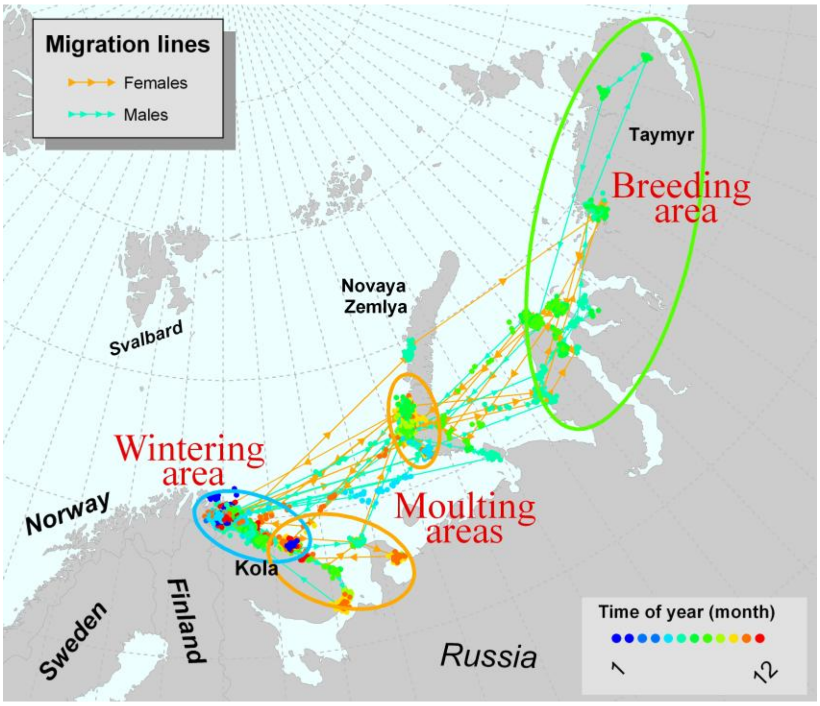

Figure 2.4.29. Steller's Eider migration patterns (Source: www.seapop.no).

Table 2.4.3. Breeding population estimates of seabirds in the Barents Sea Region (pairs).

Species		Ecological group	Regions							Total
			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	2,000-3,000	500,000-1, 000,000	500,000-1,000,000
European storm-petrel	*Hydrobates pelagicus*	PSu	1,000-10,000	0	0	0	0	0	0	1,000-10,000
Leach's storm petrel	*Oceanodroma leucorhoa*	PSu	100-1,000	0	0	0	0	0	0	100-1,000
Northern gannet	*Morus bassanus*	PSu	1,750	150 -250	0	0	0	0	0	1,900-2,150
Great cormorant	*Phalacrocorax carbo*	CFi	10,000	1,200	370	0	0	0	0	11,570
European shag	*Phalacrocorax aristotelis*	CFi	6,000	350-400	0	0	0	0	0	6,350-6,400
Common eider	*Somateria mollisima*	CBe	100,000	3,000-4,000	9,500	1,500	25,000	1,000-2,000	17,000	157,000-159,000
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	?	?
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	10-50	0	500 –1,000	540-1,100
Sabine's gull	*Xema sabini*	PSu	0	0	0	0	0	0	2-10	1-10
Mew gull	*Larus canus*	CSu	10,000	500	3,700	?	0	0	1-5	14,200
Lesser Black-backed gull	*Larus fuscus*	PSu?	<300		>3200	0	0	0	1-5	3,500
Herring gull	*Larus argentatus*	CSu	100,000	17,500	5,100	0	0	0	1-5	122,600
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	4,000-10,000	9,000-15,000
Great black-backed gull	*Larus marinus*	CSu	15,000	7,500	330	1	1	0	50-150	22,930
Black-legged kittiwake	*Rissa tridactyla*	PSu	250,000	< 87,000	40-50	150-200	40,000-50,000	>30,000	270,000	682,000
Ivory gull	*Pagophila eburnea*	PSu	0	0	0	0	0	2-3,000	200-750	2,200-3,750
Common tern	*Sterna hirundo*	CSu	1,000	0	few	0	0	0	0	>1,000
Arctic tern	*Sterna paradisaea*	CSu	10,000	<10,000	33,000	> 1,000	?	> 1,000	<10,000	65,000
Common guillemot	*Uria aalge*	PDi	<15,000	7,800-8,400	0	0	750	0	80,000	104,000
Brünnich's guillemot	*Uria lomvia*	PDi	<1,500	1,800	0	0	250-500,000	25,000	850,000	1,250,000
Razorbill	*Alca torda*	PDi	<15,000	100-1,000	3,870	0	1-10	0	100	19,600
Black guillemot	*Cepphus grylle*	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	30,000-50,000	25,0000	>1,000,000	>1,010,000
Atlantic puffin	*Fratercula arctica*	PDi	900,000	<5,000	1-2	0	>100	0	10,000	910,000

The high density of seabirds 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*. The Barents Sea area represents an ecoton from a North-Atlantic ecosystem in the south via the Polar front to an Arctic ecosystem in the north. In the north and east, the marginal ice-zone is an 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). The seabird communities in south and west depend 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 guillemots and little auks dominate in the north.

Together with the little auk, the Brünnich’s guillemot is probably the most numerous seabird in the Barents Sea Region. The largest colonies (several over 100 000 pairs) are on the Spitsbergen, Hopen, Bear Island and the west coast of Novaya Zemlya. The Brünnich’s guillemots generally winter in waters off Iceland, Greenland and Newfoundland (Canada), although birds from Novaya Zemlya and Franz Josef Land probably remain in the Barents Sea throughout the year. Outside the breeding season Brünnich’s guillemots 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.

A crude estimate of more than one million pairs has been made for the Barents Sea little auk population, 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. Outside 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.

The black-legged kittiwake is the most common gull in the Barents Sea region and breeds in all sub-regions. It is also the most numerous species of gull in the world, and the most oceanic in its habits. The total breeding population in the Barents Sea region is estimated to be 680 000 pairs. It can be observed in all coastal areas as well as at sea, including ice-filled waters. The largest colonies are found on Bear Island, 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, the composition of the 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 the north-western part 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 make long foraging trips. Fulmars breeding on Bear Island are known to feed in the central Barents Sea as well as along the coast of North Norway during the chick-rearing period (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 discards and offal. In the Arctic, the fulmar can be seen both in open seas areas and in ice-filled waters.

In the Barents Sea region, the Atlantic puffin breeds primarily in North Norway and western Murman coast, but also in small scattered colonies in Novaya Zemlya, Spitsbergen and Bear Island. In the autumn, puffins gather in the Barents Sea. The wintering areas for the different populations are not known, but many birds winter in the southern Barents Sea and further to the south in the Norwegian Sea (Figure 2.4.30; www.seapop.no). The Atlantic puffin feeds 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. In the nonbreeding season they are pelagic in their distribution and feeding habits.

The common eider is the most numerous 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. The 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 shallows are also part of their prey. 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 Island (Bakken et al., 2003). Some birds may spend the winter in the 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 the breeding range, leaving only the most easterly regions. In mid winter, the numbers of common eiders in eastern Finnmark, Norway, increases with about 50 000 individuals, indicating that birds from Russian populations move to 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 show 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 e.g. in the high-Arctic archipelagos of Svalbard and Franz Josef Land and rich vegetation is found below the seabird breeding colonies, which is grazed by reindeers *Rangiferus rangiferus*, geese (*Branta* spp. and *Anser brachyrhynchos)* and ptarmigan *Lagopus mutus*.

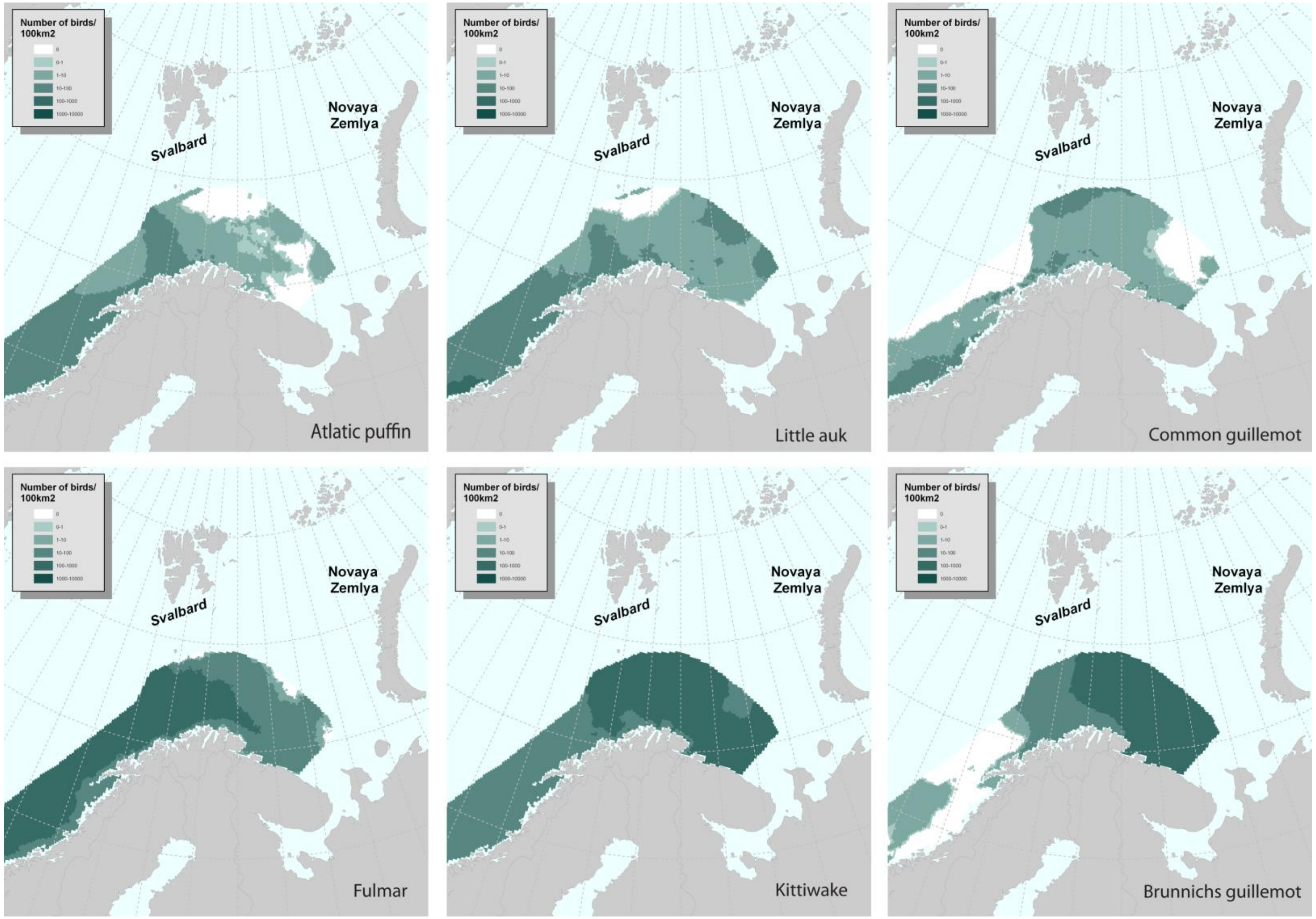

Figure 2.4.30. Seabird winter distribution in open sea (Source: www.seapop.no).

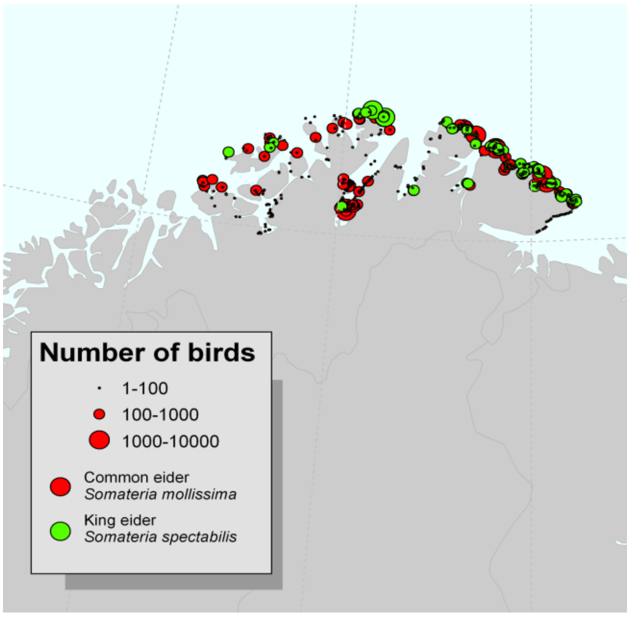

Figure 2.4.31. Common and King Eider distribution in Finnmark, March 1999 (Source: www.seapop.no).

2.4.9 Infectious organisms

S. Marasaev (SMG), A. B. Karasev (PINRO), V.V. Kuklin (MMBI), and M. Tryland(NVH)

This chapter summarises some of the knowledge we have about infectious organisms in the Barents Sea. Information is given on the parasite species that occur in fish, seabirds, snails the red king crab and the impact that some of these parasites have on their hosts is also discussed. A short summary is also given of viral infections and their possible impact in the Barents Sea.

2.4.9.1 Parasitophauna of fish of the Barents Sea

This work summarizes information on parasites of 91 species of fish from personal knowledge and available literature (Karasev, 2003). There are 10 types of parasites found in the fish of the Barents Sea: *Mastigophora* (*Kinetoplastomonada*, *Parasitomonada*), *Sporozoa* (*Coccidea*), *Microsporidia* (*Microsporea*), *Myxozoa* (*Myxosporea*), *Ciliophora* (*Peritricha*), *Plathelminthes* (*Monogenoidea*, *Gyrocotylida*, *Cestoda*, *Aspidogastrea*, *Trematoda*), *Nemathelminthes* (*Nematoda*), *Acanthocephales* (*Palaecanthocephala*), *Annelida* (*Hirudinea*), *Arthropoda* (*Crustacea*) – total of 235 species, from 140 genera , 74 families, 33 groups, 15 classes (see Table 2.4.4).

It is hard to determine which groups of parasitic organisms that play an important role in the population dynamics of their hosts. If there are large changes in the ecosystem, several groups of infectious organisms are capable of causing unpredictable effects on the ecosystem, including serious declines in host population.

The parasites found in the Barents Sea parasites that are considered the largest potential threats to human health are larvae stages of *Cestoda* (*Diphyllobothrium* and *Pyramicocephalus* genera), *Nematoda* (*Anisakis* and *Pseudoterranova* genera) and *Palaea*

Table 2.4.4. Taxonomic composition of the Barents Sea fishes' parasitofauna

Class	No of groups	% from all groups	No of families	% from all families	No of generations	% of all generations	No of species	% from all species
Kinetoplastomonad	2	6.1	2	2.7	2	1.4	2	0.9
Parasitomonada	1	3.0	1	1.4	1	0.7	1	0.4
Coccidea	2	6.1	2	2.7	3	2.1	5	2.1
Microsporea	1	3.0	2	2.7	3	2.1	4	1.7
Myxosporea	1	3.0	10	13.5	16	11.4	38	16.2
Peritricha	1	3.0	1	1.4	2	1.4	9	3.8
Monogenoidea	7	21.2	9	12.2	14	10.0	34	14.5
Gyrocotylida	1	3.0	1	1.4	1	0.7	4	1.7
Cestoda	4	12.1	11	14.9	17	12.1	22	9.4
Aspidogastrea	1	3.0	1	1.4	1	0.7	1	0.4
Trematoda	5	15.2	14	18.9	31	22.1	42	17.9
Nematoda	2	6.1	4	5.4	7	5.0	11	4.7
Palaeacanthocephala	2	6.1	2	2.7	2	1.4	4	1.7
Hirudinea	1	3.0	1	1.4	9	6.4	13	5.5
Crustacea	2	6.1	13	17.6	31	22.1	45	19.1
Total	33	100	74	100	140	100	235	100

canthocephala (*Corynosoma* genera). Only nematode larvae of *Anisakis* and *Pseudoteranova* genera are present in the fish muscles tissue (Korotaeva, 1991; Serdyukov, 1993; Solovyeva, Krasnyh, 1989).

According to current research, levels of parasitic infestation in fish with organisms that are potentially dangerous for human health, has not increased in recent years. In some cases there is even a decrease in infestation level. This may be a result of an improving state of the capelin stock, which is often the main food base for the commercially important fish species.

2.4.9.2 Helminthofauna of the Barents Sea seabirds

In surveys of 18 species of seabirds, 82 species of helminthes were recorded, 28 trematoda species, 37 cestoda species, 12 nematods, 5 species of the order *Acanthocephala*. There are 74 species of helminthes in birds from the Murman coast, and 39 of them are characteristic for that area only. There are 10 (1) species from Novaya Zemlja and 28 (7) from Svalbard. 6 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 7 species of birds. These are *Somateria mollissima, Polystica stellery, Calidris maritima, Rissa tridactyla, Larus argentatus, L. hyperboreus* and *Cepphus grylle.*

The helminthofauna of Barents Sea seabirds consists mostly of species where the life cycle depend on coastal ecosystems. Invertebrates and fish from the littoral and upper sub littoral complex serve as their intermediate hosts. There are some exceptions to this: Cestodes from the *Tetrabothriidae* and *Dilepididae* families. These are able to complete their entire life cycle in the open sea.

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

The trematode fauna in seabirds of the Arctic islands is quite poor. Levels of infection are also quite low. The reason is the absence of the intermediate hosts (mollusks) and unfavorable environmental conditions. At the same time many cestode species from *Dilepididae, Hymenolepididae* and *Tetrabothriidae* and some *Acanthocaphala* families 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. Therefore, 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 avian helminthofauna of Murman. There are changes in species of helminths present as well as a significant drop in the trematode and cestode infestation levels. This is a result of decrease in bird numbers and change in their foodbase. Capelin (*Mallotus villosus*) over-fishing has also played a significant role as it is a main foodbase for many species.

Pathogenicity of helminthes for the birds of the Barents Sea
Infestation with helminthes leads to changes in protein, lipid, carbohydrate metabolism and mineral levels in birds of the Barents Sea. Presence of intestinal parasites causes changes in physiological condition of blood and dysfunction of liver and kidney.

The most pronounced metabolic changes were recorded in birds infected with cetodes from the *Hymenolepididae* and *Tetrabothriidae* families, together with the infestation by species from *Dilepididae* и *Tetrabothriidae* families, trematodes from *Microphallidae* family and joint invasion by trematodes from *Microphallidae* and *Heterophyidae* families (Kuklin and Kuklina, 2005).

Research has shown that the most intensive changes in metabolic processes of the birds 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 undeveloped immune system.

2.4.9.3 Helminthofauna of pinnipeds and cetaceans of the Barents Sea
There are 32 species of helminthes found in the following species: bearded seal (*Erignathus barbatus*), ringed seal (*Phoca hispida*), hooded seal (*Pagophilus groenlandicus*) and beluga whale (*Delphinapterus leucas*). Helminthofauna consists of *Trematoda* (6 species), *Cestoda* (8), *Nematoda* (11) and *Acanthocephala* (7) (Treschev, 1970).

The parasites that are generally most pathogenic for pinnipeds and cetaceans are from *Nematoda* and *Acanthocephala* groups dwelling in the gastrointestinal tract (stomach and small intestines). Infestation levels of these parasites can reach 90 % and more. It can lead to formation of ulcers, tumours and damages to the walls of the gastrointestinal tract and ultimately death. Such cases have been registered in wild and captive animals. Parasites from *Anisakis* and *Contracaecum* (*Nematoda*) and *Corynosoma* (*Acanthocephala*) are generally the most pathogenic ones from these groups. Young animals become infected immediately after switching from milk to fish diet. Degree of infestation grows quickly and young organism is often unable to deal with the invasion. Most intensive infestation occurs in those species of marine mammals that consume fish found near the shore. This is because the percent of infestation with helminths that are dangerous for them are much higher in the species of fish found here.

2.4.9.4 Trematodofauna of benthic gastropods of the Barents Sea
Overall, currently known fauna of partenides and trematode larvae, present in the benthic gastropods, includes 29 species from 9 families of trematodes. (Chubrik, 1966; Podlipaev, 1979; Galaktionov and Marasaev, 1986; 1990, etc.) (Table 2.4.5).

The general trend of infestation of benthic gastropods with trematoda species is the focal distribution of invasion, and it applies to marine and fresh water ecosystems alike (Ginetsinskaya, 1983). Distribution of trematode foci in gastropods of the Barents Sea is the following: In the northern and central parts of the sea trematode foci is absent; towards south, with the decrease of the sea depth, in the shallow water and on banks, there are some localized areas of infestation of gastropods with parasites that use fish as a final host.

Table 2.4.5. Fauna of trematodes parasitizing in the benthic gastropods of the Barents Sea.

Family	**Quantity of species**	**The final owner**
Acanthocolpidae	2	Fishes
Opecolidae	4	
Zoogonidae	1	
Lepocreadiidae	2	
Hemiuridae	3	
Renicolidae	2	Birds
Notocotylidae	3	
Microphallidae	9	
Himasthlidae	1	
The regular accessory is unknown	2	Fishes

In coastal Murman areas of, infections are found near littoral and sublittoral bays, gulfs and nearby islands. In such areas, there is a higher percent of infection in mollusks and a high diversity of trematode species. These are mainly parasites that use birds as their final host.

No infestation has been found in the littoral zone of the Pechora Sea as there is no macrobenthos present. Parasitic foci are located in the vast areas of the shallow water. Bird parasites are dominating there due to the ecological conditions of the region.

The shallow waters of the Pechora Sea aids formation of the foci of many species of helminthes. Infestation levels in gastropods is higher in this area than in the coastal Murman area. Invasion foci are formed due to the uneven spatial distribution of invertebrates and vertebrates, serving as intermediate and final hosts for parasites. Many different factors are required for a successful infestation, such as concentration of intermediate and final hosts and certain hydrodynamic, hydrological and hydrochemical regimes. Such a set of favourable conditions occurs locally.

The most pathogenic parasites in known foci are species from the *Microphallus* genus (*Microphallidae* family), which can be pooled into the group «pygmaeus». Infestation with these parasites leads to sterilization of the first host (mollusk). There is a very high level of infestation among older molluscs, which can reach up to 50-60 % (Galaktionov, 1982). Such a high level of invasion is observed in Littorina species living in small bays, especially inner areas and vast regions of the Pechora Sea. Secondly, infestation levels of young birds of some species (*Somateria molissima*) is almost 100%, and intensity of invasion is such, that it leads to high mortality, sometimes reaching 40% (Bianki, et al., 1979). Weak immune systems of young birds is likely a reason for this.

2.4.9.5 Parasitofauna *Paralithodes camtshaticus* of the Barents Sea

Presently, king crab (*Paralithodes camtshaticus)* has formed an independent population in the Barents Sea after the introduction of the species from the Pacific Ocean. Research conducted on various organs and tissues of the crab has shown a presence of the parasites listed in Table 2.4.6.

Table 2.4.6. Parasites Paralithodes camtshaticus in the Barents Sea.

	Quantity of kinds	The certain species	Localization
Acanthocephala	4	*Polymorphus botylus 1, orynosoma strumosum, Echinorhynchus gadi, Acanthocephalus sp.*	stomach, intestines, cavity of a body
Nematoda	4	*Anisakis simplex 1, seudoterranova decipiens 1*	stomach, hepatopancreas, a cavity of a body
Monogenoidea	1		hepatopancreas
Cestoda	1		stomach
Turbellaria	1		gills
Hyrudinea	2	*Johanssonia arctica, Crangonobdella fabricii*	surface of a body

No parasites that infect the king crab in the Pacific were found in the king crab from the Barents Sea. Therefore, results of the research demonstrate that introduced crab has not become a source of any introduced parasites in the Barents Sea (Bakay, 2003).

A question regarding a possible increase in numbers of *Trypanosoma* cases in Barents Sea fish due to the increasing numbers of king crab population remains open as the Norwegian and Russian scientists have different opinion on this matter (Karlsbakk et al., 1999; Karlsbakk, 2005; Hemmingsen et al., 2005; Bakay and Karasev, 2008).

2.4.9.6 Bacteria and viruses

Bacteria and viruses are widespread pathogens in the Barents Sea. Bacteria of the genus *Brucella* are widely distributed among marine mammals, including the polar bear. A recent investigation revealed high prevalences of anti-*Brucella* antibodies (35%) and *Brucella-bacteria* /*Brucella pinnipedialis*; 38%) in hooded seals. *Phocine distemper* virus (PDV) can be highly pathogenic in seals. No such disease has been seen in seals in the Barents Sea, but antibodies have been detected in polar bears (8%) and in harbour seals and walrus at Svalbard (5% and 31%, respectively). *Francisella philomiragia* subsp. *noatunensis* is an emerging pathogen in farmed cod and may also become a threat to wild cod. In general, viral and bacterial pathogens are poorly investigated in the Barents Sea. The pathogens listed here are just examples of what can be found, and shows that virus and bacteria may be important components of the ecosystem.

2.4.10 Rare and threatened species

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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, 2008), the Russian Red Data book (Danilov-Danilyan et al., 2001) and/or the Norwegian Red List (Kålås et al., 2006). In this report the groups of species included are restricted to mammals, birds and fish species. This is caused by the general lack of knowledge and lack of relevant assessments for the other taxonomic groups for 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 to a minor degree such assessments. For future reports the goal should be to include a far broader spectre of taxonomic groups.

This chapter includes species that either have very small populations or species that have recently undergone considerable population decline (or are expected to do so in the close future). The assessments are done by use of the IUCN criteria (IUCN 2001, 2003), but the Global, the Russian and the Norwegian lists can not be directly compared. The Global list is the global assessment (IUCN 2001), and includes assessments for the global population of the actual species. The Norwegian Red List is a regional red list using the IUCN categories and criteria on a Norwegian scale (IUCN 2003), i.e. covering the Norwegian populations and 'rescuing' effects from neighbouring populations. Framework for the Red Data Book of the Russian Federation is based on the Federal law “On the Environmental Protection" (10 January 2002), on the Federal law "About animal world" (5 May 1995), and on the Decree of the Government of the Russian Federation # 158 (19 February 1996), which stated the Red Data Book of the Russian Federation to be an official document providing information about the 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.

However, all these lists are closely related and have high relevance for the conservation of biodiversity.

We here present the relevant species in a table (Table 2.4.7) that in addition to the Red List categories also gives information about the species status on relevant international conventions or agreements. But be aware that all the 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 18 mammal species. We don't present more details on particular species in this chapter. Such information is included in the main chapters on fish, birds, and mammals.

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. ırwegian 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 ategory & Threat Status
1	2	3	4	5	6	7	8	9
Birds cont.								
Rissa tridactyla		No	VU/A2b		3	2	+	NON-SPEC,S
Pagophila eburnea	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.								
Balaenoptera musculus	EN/A1abd	1	NT	1	2	1		
Balaenoptera physalus	EN/A1d	2		1	2			
Delphinapterus leucas	NT		DD					
Eubalaena glacialis	EN/D1	1	RE			Eubalaena glacialis	EN/D1	1
Halichoerus grypus			NT			Halichoerus grypus		
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				
Species	**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							

2.4.11 Introduced species

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Invasion of alien species – spread of the representatives of various groups of living organisms beyond their primary habitats - is global in nature. Invasive species often act as biological pollutants, and may threaten an ecological security of the 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 the ecosystem outside of their original (usually natural) range. Therefore, the following examples represent different modes of biological invasion:

- natural movement associated with the population dynamics and climatic changes;
- intentional introduction and reintroduction;
- accidental introduction with the ballast waters and along with the intentionally introduced species, etc.

In the beginning of this century, due to the expansion of habitat range of fish from the southern boreal complexes, the following species, that can be considered temporary invasive species, appeared in the Barents Sea: snake pipefish (*Eutelurus aequoreus*), sail ray *(Dipturus linteus)*, whiting (*Merlangus merlangus*), grey gurnard (*Eutrigla gurnardus*), megrim (*Lepidorhombus whiffiagonis*), However, the mentioned fish species can only, obviously, occur in the Arctic region waters of the Barents Sea in the period of anomalous climate warming.

On the other hand, invasive species that were deliberately or accidentally introduced to the Barents Sea as a result of human activity will probably stay in the Barents Sea for a long period of time. So, a special attention is paid to them in this chapter.

Also, *Aporrhais pespelecani* sp (Linnaeus, 1758) was recorded on the Murman coast of the Barents Sea. The finding of established population of the mollusc significantly (nearly 1000 km) extends its range eastward. A few species of gastropods were recently recorded for the first time on the Murman coast of Russia. These are four species of nudibranchs (Martynov et al., 2006), undoubtedly migrating eastward due to the warming of the Arctic ocean.

However, under various scenarios of the climate change processes in the Arctic, such period may last for a long time and there is a need to explore possibilities of range expansion of other boreal species and their impacts on indigenous communities.

Further, it makes sense to elaborate on the most economically important 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 transporation/distribution (cryptogenic species):	
Gyrodactylus salaries	*Plathyhelminthes/Trematoda/Monopisthocotylea*

2.4.11.1 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 Russian-Norwegian Fisheries Commission (JRNFC).

2.4.11.2 Snow crab (*Chionoecetes opilio*)

This species has not been deliberately introduced into the Barents Sea and is therefore considered to be an autoinvasive 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 aim of this chapter, is to give a background description of the different human activities as they are generally performed in the Barents Sea. The general impact that these activities have on the ecosystem will be dealt with in a later chapter (2.6.3) and is thus not discussed with here. The current status of the different activities and their impact as revealed by the most recent data is described in chapter 4.4.

2.5.1 Fisheries and other harvesting

K. Nedreaas (IMR), K. V. Drevetnyak (PINRO), C. Kvamme (IMR), K. M. Sokolov (PINRO), and S. Aanes (IMR)

Fishing is the largest human impact to the fish stocks in the Barents Sea, and thereby the functioning of the whole ecosystem. However, the observed variation in both fish species and ecosystem is also impacted by other effects such as climate and predation (see chapter 2.6.2.5). In the Barents Sea the catch of the major fish species by the fishing fleet in 2008 was about 900 000 tonnes.

2.5.1.1 General description of the fisheries

The major demersal stocks in the Northeast Arctic include cod, haddock, saithe, and shrimp. In addition, redfish, Greenland halibut, wolffish, and flatfishes (e.g. long rough dab, plaice) are common on the shelf and at the continental slope, and ling and tusk at the slope and in deeper waters. In 2008, catches of nearly 900 thousand tonnes (provisional figures) are reported from the stocks of cod, haddock, saithe, redfish, and Greenland halibut, which is a decrease of 10% as compared to 2006. An additional catch of about 40 000 tonnes was taken from the stocks of wolfish and shrimp. The annual fishing mortalities F (the mortality rate is linked to the proportion of the population being fished by 1-e-F) for the assessed demersal fish stocks show large temporal variation within species and large differences across species from 0.1 (≈10% mortality) for some years for Sebastes marinus to above 1 (≈63% mortality) for some years for cod (Figure 2.5.1.) The major pelagic stocks are capelin, herring, and polar cod. There was no fishery for capelin in the area in 2004-2008 due to the stock's poor condition, but in 2009 the stock is again sufficient sound to support a quota of 390 000 tonnes.

Russia, as the only nation currently fishing polar cod, fished 8 190 tonnes polar cod in 2008. Norwegian spring spawning herring is the largest stock inhabiting the Northeast Arctic with its spawning stock estimated to 12.6 million tonnes in 2009. 1.5 million tonnes were fished from this stock in 2008, of which about 280 000 tonnes were caught near the Norwegian coast in the south-western part of the Barents Sea. The highly migratory species blue whiting and mackerel extend their feeding migrations into this region, and in 2007 about 65 000 tonnes mackerel and 120 000 tonnes blue whiting were caught in the area, none of this, however, within the Barents Sea. Species with relatively small landings include salmon, Atlantic halibut, hake, pollack, whiting, Norway pout, anglerfish, lumpsucker, argentines, grenadiers, flatfishes, dogfishes, skates, crustaceans, and molluscs.

The most widespread gear used in the central Barents Sea is bottom trawl, but also long line and gillnets are used in the demersal fisheries. The pelagic fisheries use purse seine and pelagic trawl. Other gears more common along the coast include handline and Danish seine. Less frequently used gears are float line (used in a small but directed fishery for haddock along the coast of Finnmark, Norway) and various pots and traps for fish and crabs. The gears used vary with time, area and country, with Norway having the largest variety because of the coastal fishery. For Russia, the most common gear is bottom trawl, but a longline fishery mainly directed at cod and wolffish is also present. The other countries mainly use bottom trawl.

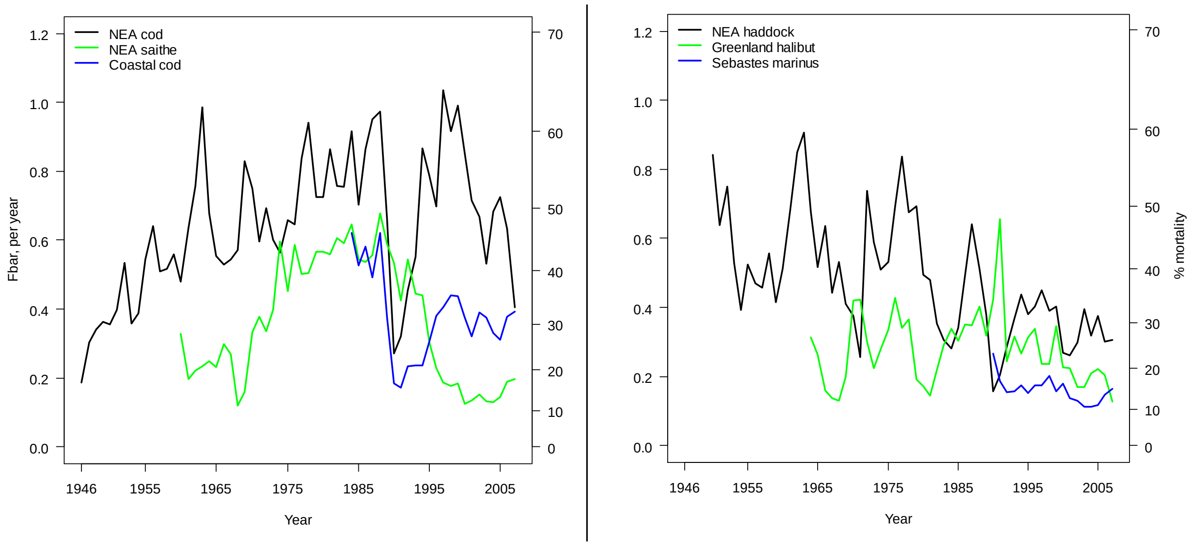

Figure 2.5.1. Time series of annual average fishing mortalities for Northeast Arctic cod (time period 1946-2007, average for ages 5-10), Northeast Arctic saithe (time period 1960-2007, average for ages 4-7), coastal cod (1984-2007, average for ages 4-7), Northeast Arctic haddock (time period 1950-2007, average for ages 4-7), Greenland halibut (time period 1964-2007, average for ages 6-10) and *Sebastes marinus* (time period 1990-2007, average for ages 12-19).

For most of the exploited stocks an agreed quota is decided (TAC), and also a number of additional regulations are applied. The regulations differ among gears and species and may be different from country to country, and a non-exhaustive list as well as a description of the major fisheries in the Barents Sea by species can be found in Table 2.5.1.

2.5.1.2 Mixed fisheries

The demersal fisheries are highly mixed, usually with a clear target species dominating, and with low linkage to the pelagic fisheries (Table 2.5.2). Although the degree of mixing may be high, the effect of the fisheries varies among the species. More specifically, the coastal cod stock and the two redfish stocks are presently at very low levels. Therefore, the effect of the mixed fishery will be largest for these stocks. In order to rebuild these stocks, further restrictions in the regulations should be considered (e.g. closures, moratorium, and restrictions in gears).

Successful management of an ecosystem includes being able to predict the effect of a mixed fishery on the individual stocks, and ICES is requested to provide advice which is consistent across stocks for mixed fisheries. Work on incorporating mixed fishery effects in ICES advice is ongoing and various approaches have been evaluated (ICES 2006/ACFM:14). At present such approaches are largely missing due to a need for improving methodology combined with lack of necessary data. However, technical interactions between the fisheries can be explored by the correlation in fishing mortalities among species (Figure 2.5.2). The correlation in fishing mortality is positive for Northeast Arctic cod and coastal cod, and for haddock and coastal cod confirming the linkage in these fisheries. There is also a significant relationship between saithe and Greenland halibut although the linkage in these fisheries is believed to be low (Table 2.5.2). The relationships between the other fishing mortalities are scattered and inconclusive. In case of strong dependencies in fishing mortalities this method can, in principle, be used to produce consistent advice across species concerning fishing mortality. It is however too simple since this correlation is influenced by too many confounding factors whose effect cannot be removed without a detailed analysis of data with a higher resolution (e.g. saithe and Greenland halibut, and changes in stock distribution (ICES 2006/ACFM:14).

A further quantification of the degree of mixing and impact on individual stocks requires detailed information about the target species and mix per catch/landing and gear. Such data exist for some fleets (e.g. the trawler fleet), but is incomplete for other fleets. The Russian and Norwegian trawl fleet catches show spatial and temporal differences in both composition and size as well as large differences between countries (Figures 2.5.3-2.5.6). In the north eastern part of the Barents Sea the major part of the Russian catches consists of cod, whereas the Norwegian catches include a large proportion of other species (mainly shrimp). In the most western part of the Barents Sea, the Norwegian catches consist of Sebastes mentella and Greenland halibut in addition to cod, whereas the Russian catches mainly consist of cod and haddock. The main reason for this disparity is the difference in spatial resolution of the data; the Norwegian strata system extends further west and thus covers the fishing grounds of Greenland halibut, whereas the Russian strata does not. The Norwegian trawl fishery along the Norwegian coast includes areas closer to the coast and is also more southerly distributed where other species are more dominant in the catches (e.g. saithe).

Estimates of unreported catches of cod and haddock in 2002-2008 indicate that this has been a considerable problem which now seems to be decreasing. A continuous control and surveillance of this problem is necessary. Discarding of cod and haddock (and in some years also saithe) is thought to be significant in periods, although discarding of these, and a number of other species, is illegal in Norway and Russia. Data on discards are scarce, but attempts to obtain better quantification are ongoing.

Table 2.5.1. Description of the fisheries by gears.

The gears are abbreviated as: trawl roundfish (TR), trawl shrimp (TS), longline (LL), gillnet (GN), handline (HL), purse seine (PS), Danish seine (DS) and trawl pelagic (TP). The regulations are abbreviated as: Quota (Q), mesh size (MS), sorting grid (SG), minimum catching size (MCS), maximum by-catch of undersized fish (MBU), maximum by-catch of non-target species (MBN), maximum as by-catch (MB), closure of areas (C), restrictions in season (RS), restrictions in area (RA), restriction in gear (RG), maximum by-catch per haul (MBH), as by-catch by maximum per boat at landing (MBL), number of effective fishing days (ED), number of vessels (EF).

Species	**Directed fishery by gear**	**Type of fishery**	**Landings in 2008 (tonnes)**	**As by-catch in fleet(s)**	**Location**	**Agreements and regulations**
Capelin	PS, TP	seasonal	4[B]	TR, TS	Northern coastal areas to south of 74°N	Bilateral agreement, Norway and Russia
Coastal cod	GN, LL, HL, DS	all year	23 841[C]	TS, PS, DS, TP	Norwegian coast line	Q, MS, MCS, MBU, MBN, C, RS, RA
Cod	TR, GN, LL, HL	all year	486 883[C]	TS, PS, TP, DS	North of 62°N, Barents Sea, Svalbard	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Wolffish[2]	LL	all year	13 401[E]	TR, (GN), (HL)	North of 62°N, Barents Sea, Svalbard	Q, MB
Haddock	TR, GN, LL, HL	all year	146 830	TS, PS, TP, DS	North of 62°N, Barents Sea, Svalbard	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Saithe	PS, TR, GN	seasonal	197 334	TS, LL, HL, DS, TP	Coastal areas north of 62°N, southern Barents Sea	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Greenland halibut[4]	LL, GN	seasonal	14 828	TR	Deep shelf and at the continental slope	Q, MS, RS, RG, MBH, MBL
Sebastes mentella	No directed fishery	all year	19 828	TR	Deep shelf and at the continental slope	C, SG, MB
Sebastes marinus	GN, LL, HL	all year	7 187	TR	Norwegian coast	SG, MB MCS, MBU, C
Shrimp	TS	all year	25 919[E]		Svalbard, Barents Sea, Coastal	ED, EF, SG, C, MCS

A Provisional figures

B Research catch

C The total cod catch north of 62°N (480,814 t) is the sum of the NEA cod catch given in the table above (464,171 t) and the total cod catches between 62ºN and 67ºN for the whole year and between 67ºN and 69ºN for the second half of the year (16,643 t).

D The directed fishery for wolffish is mainly in ICES area IIb and the Russian EEZ, and the regulations are mainly restricted to this fishery)

Table 2.5.2. Flexibility in coupling between the fisheries. Fleets and impact on the other species (H, high, M, medium, L, low and 0, nothing). The table below the diagonal indicates what gears couples the species, and the strength of the coupling is given above the diagonal. The gears are abbreviated as: roundfish trawl (TR), shrimp trawl (TS), longline (LL), gillnet (GN), handline (HL), purse seine (PS), Danish seine (DS) and pelagic trawl (TP).

Species	Cod	Coastal cod	Haddock	Saithe	Wolffish	S. mentella	S. marinus	Greenland halibut	Capelin	Shrimp
Cod		H	H	H	M	M	M	M	L	M-H juvenile cod
Coastal cod	TR, PS, GN, LL, HL, DS		H	H	L	L	M-L	L	0-L	L
Haddock	TR, PS, GN, LL, HL, DS	TR, PS, GN, LL, HL, DS		H	M	M	M	L	0-L	M-H juvenile haddock
Saithe	TR, PS, GN, LL, HL, DS	TR, PS, GN, LL, HL, DS	TR, PS, GN, LL, HL, DS		L	L	M	0	0	0
Wolffish	TR, GN, LL, HL	TR, GN, LL, HL	TR, GN, LL, HL	TR, GN, LL, HL		M	M	M	0	M juvenile wolffish
S. mentella	TR	TR	TR	TR	TR		M	H	H juvenile Sebastes	H juvenile Sebastes
S. marinus	TR,GN, LL	TR, GN, LL	TR, GN, LL	TR, GN	TR, LL	TR		L	0	L-M juvenile Sebastes
Greenland halibut	TR, GN, LL, DS	TR, GN, LL	TR, GN, LL, DS	TR, GN, LL, DS	TR, LL	TR	TR		0	M-H juvenile
Capelin	TR, PS, TS, TP	PS, TP	TR, PS, TS, TP	PS	TP	TP	TP	None		L
Shrimp	TS	TS	TS	TS	TS	TS	TS	TS	TS	

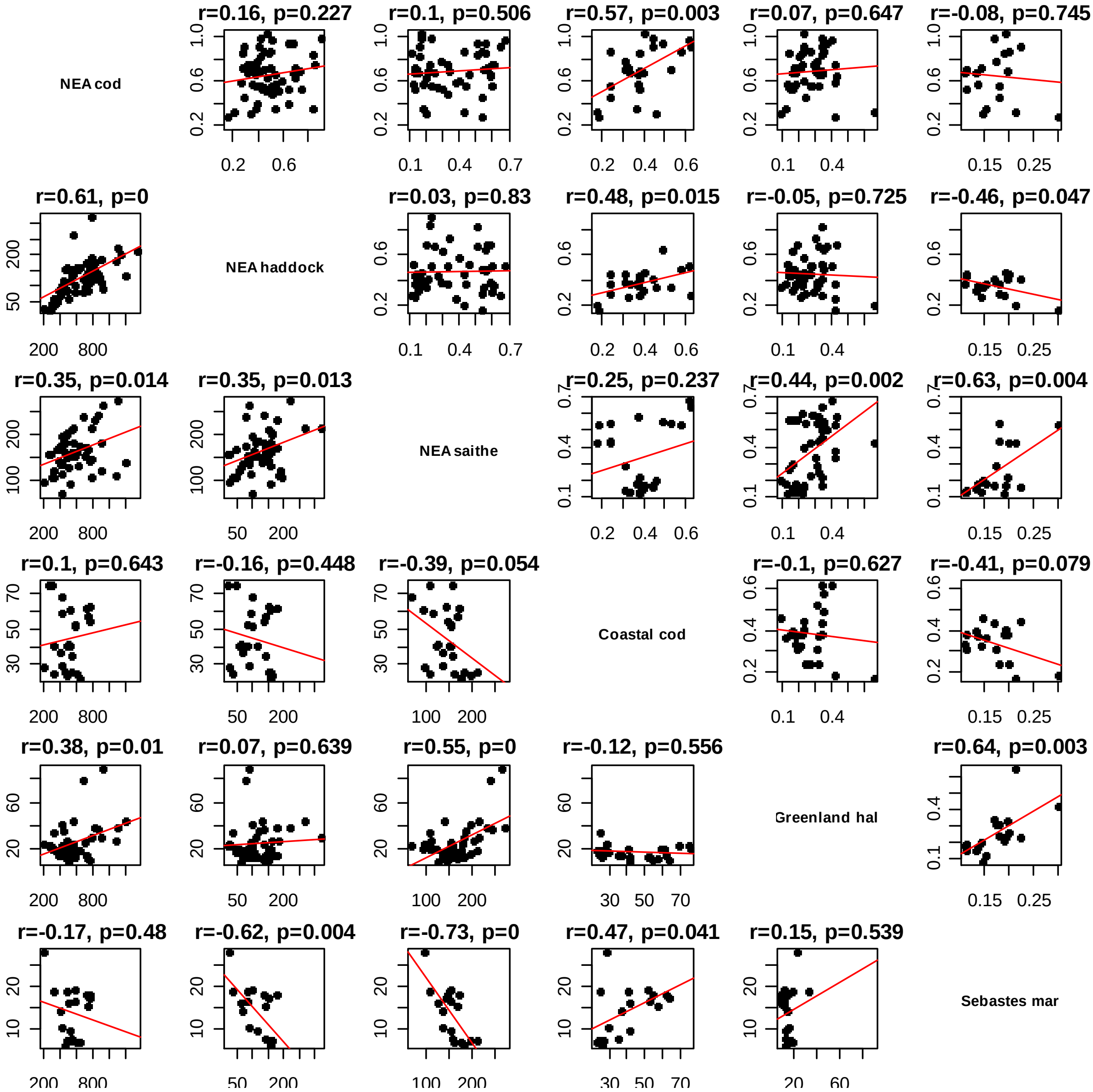

Figure 2.5.2. Pair-wise plots of annual average fishing mortalities (above diagonal) and landings (below diagonal) for overlapping time periods for Northeast Arctic cod (time period 1946-2008, average for ages 5-10), Northeast Arctic haddock (time period 1950-2008, average for ages 4-7), Northeast Arctic saithe (time period 1960-2008, average for ages 4-7), coastal cod (1984-2008, average for ages 4-7), Greenland halibut (time period 1964-2008, average for ages 6-10) and *Sebastes marinus* (time period 1990-2008, average for ages 12-19). The correlation and the corresponding p-value are given in legend

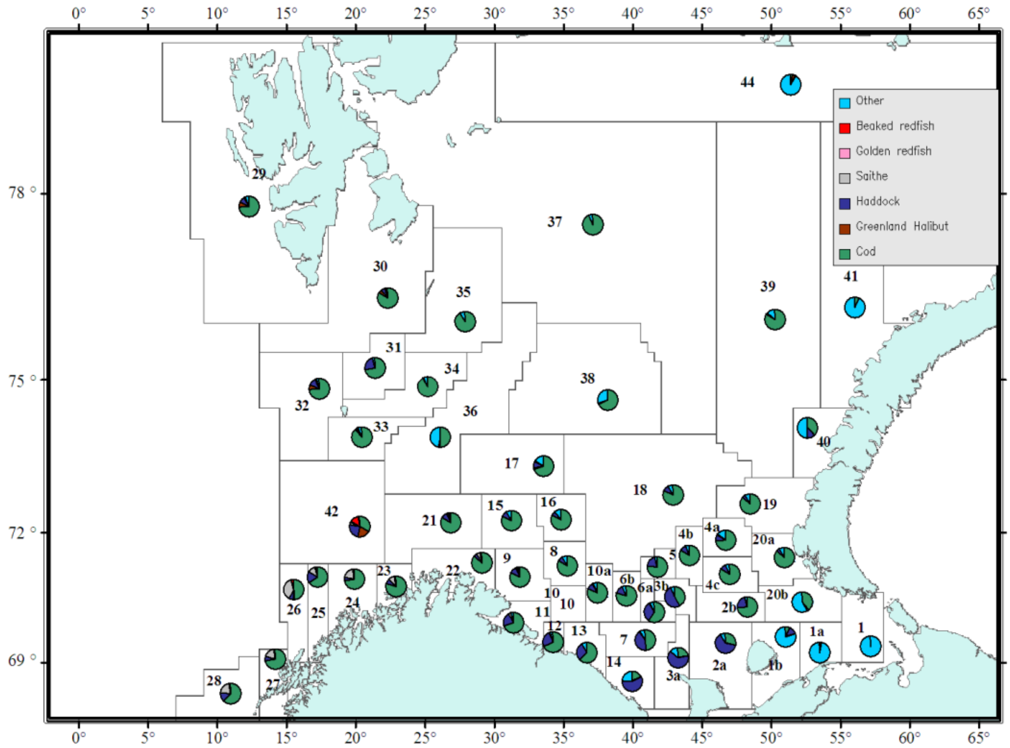

Figure 2.5.3. Relative distribution by weight of cod, haddock, saithe, Greenland halibut, golden redfish (*Sebastes marinus*), beaked redfish (*Sebastes mentella*) and other species taken by Russian bottom trawl in 1998-2007 per main area for the Russian strata system.

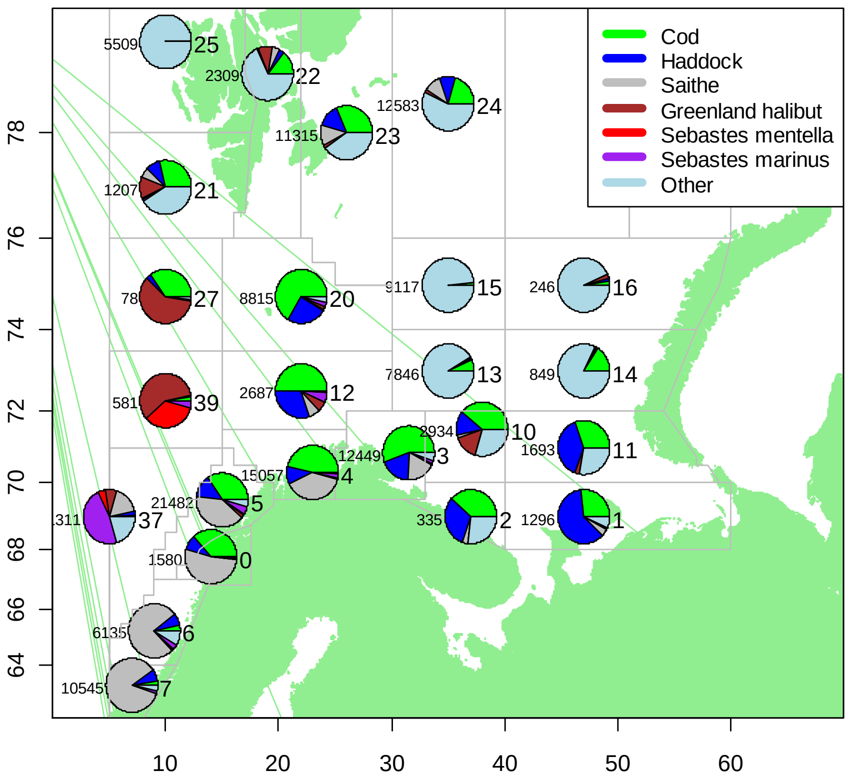

Figure 2.5.4. Relative distribution by weight of cod, haddock, saithe, Greenland halibut, *Sebastes marinus* (golden redfish), *Sebastes mentella* (beaked redfish) and other species taken by Norwegian bottom trawl in 1998-2007 per main area for the Norwegian strata system. The large number to the right of each pie diagram is the name of the stratum, while the small number to the left is the number of vessel days recorded in this area.

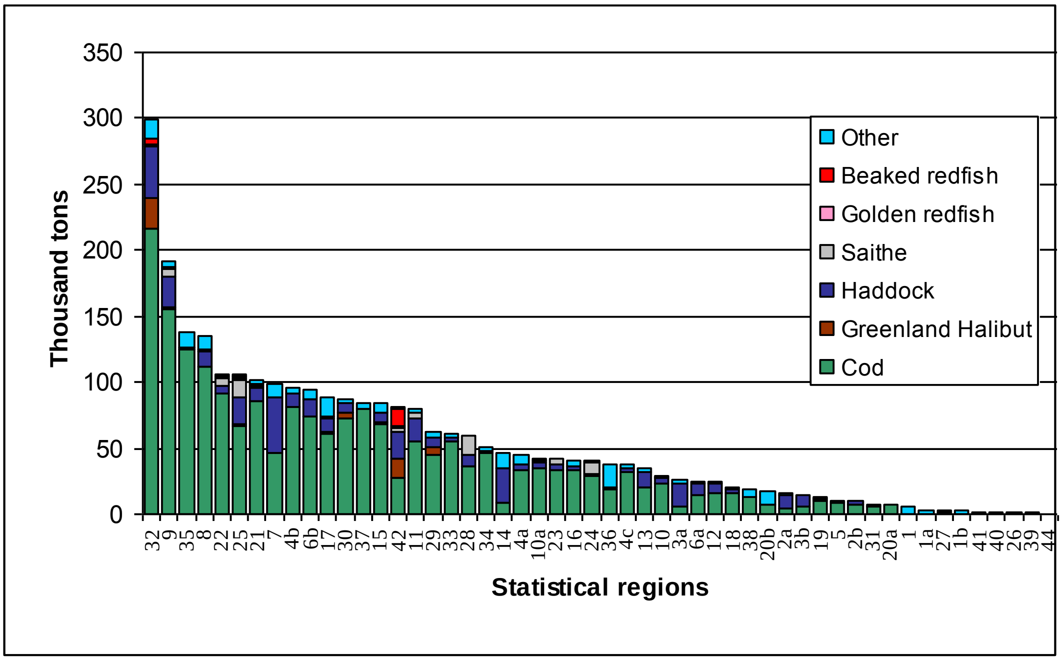

Figure 2.5.5. The Russian catch of cod, haddock, saithe, Greenland halibut, *Sebastes marinus*, *Sebastes mentella* and other species taken by bottom trawl by main statistical areas in 1998-2007, thousand tonnes. The statistical areas correspond to the areas shown in Figure 2.5.3.

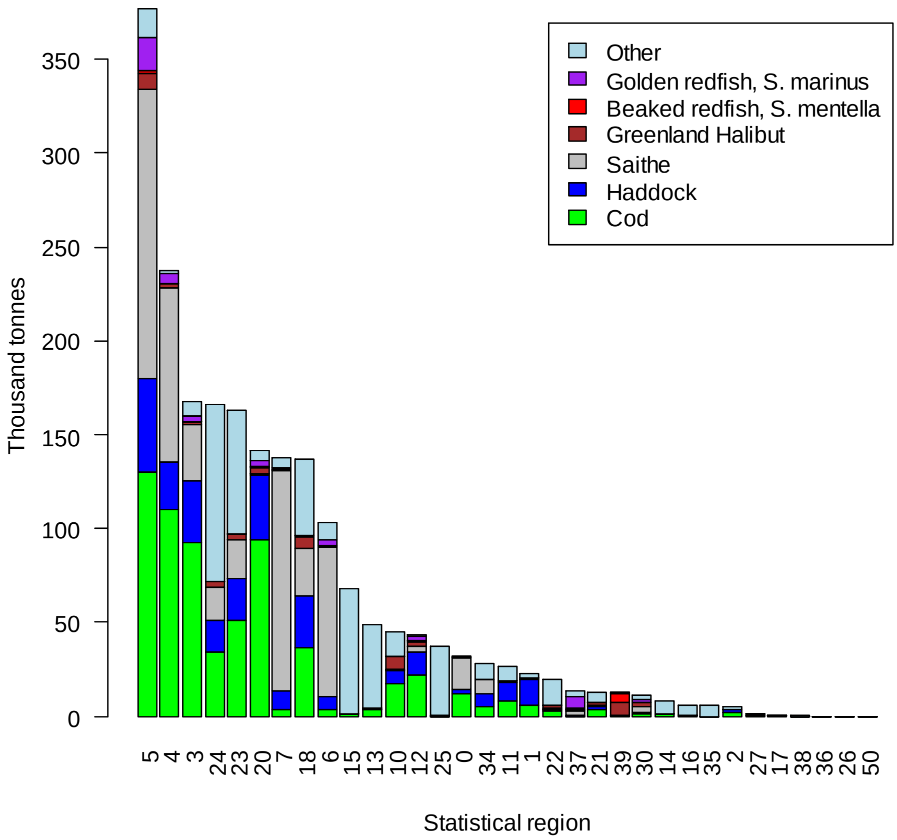

Figure 2.5.6. The Norwegian catch of cod, haddock, saithe, Greenland halibut, *Sebastes marinus*, *Sebastes mentella* and other species taken by bottom trawl by main statistical areas in 1998-2007, thousand tonnes. The statistical areas correspond to the areas shown in Figure 2.5.4.

2.5.1.3 Fleet composition

Groundfish and pelagic species

Figures 2.5.7-2.5.8 show the main fleets catching bottom and pelagic fishes in the Barents Sea and Svalbard (Spitsbergen archipelago) areas. The pelagic fishery is only conducted by Russia and Norway where both countries target the capelin. Russia has, in addition, fished polar cod with pelagic trawl (Norway has not fished this species since the early 1980s), and Norway has in recent years fished some legal sized herring in a restricted coastal purse seine fishery inside 4 nautical miles off Finnmark. Further in the south western part of the Barents Sea (south-west of a line between Sørøya and Bear Island), extending into the Norwegian Sea, an international herring fishery has been open in some seasons.

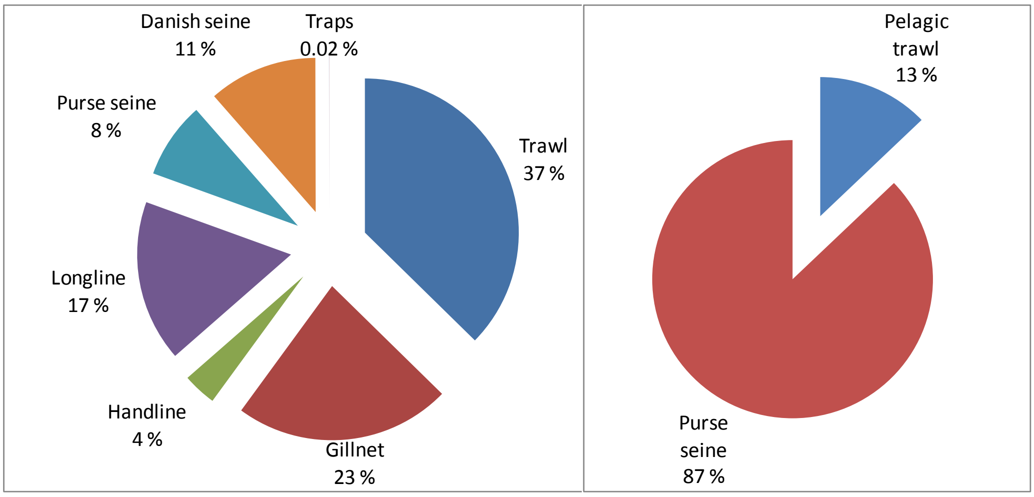

Figure 2.5.7. Gear composition of the Norwegian groundfish (2007; left panel) and pelagic capelin (2000-2008; right panel) fisheries in the Northeast Arctic. Note that the purse seine in the groundfish fishery is solely used in a coastal fishery for saithe.

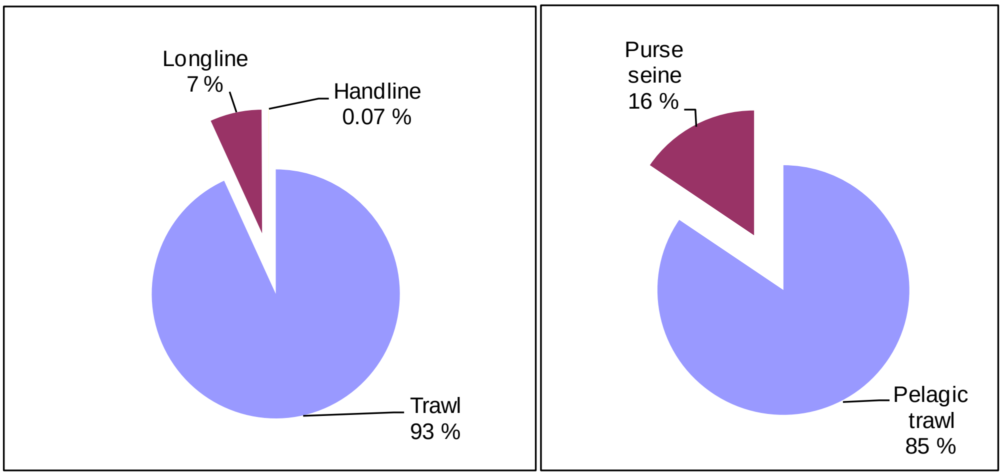

Figure 2.5.8. Gear composition of the Russian groundfish (2007; left panel) and pelagic capelin (2000-2008; right panel) fisheries in the Northeast Arctic.

The Norwegian groundfish fishery is much more diverse compared to Russia and other countries regarding the number of fleets. The trawler fleet itself is also rather diverse both within and between countries. In the Norwegian groundfish fishery several other gears are also used in addition to trawl. The gear composition also depends on which groundfish species the fishery targets. The Norwegian bottom trawl fleet catch about 30% of the Norwegian cod catch, about 40% of the haddock, and more than 40% of the Norwegian saithe and Greenland halibut catches. The Russian bottom trawl fleet catch about 100% of the Russian saithe catch, about 95% of cod and haddock, 90% of the Russian Greenland halibut catch and about 37% of wolfishes. Other countries fishing groundfish in these waters only use trawl, incl. some pair-trawling. It is mandatory in all groundfish trawl fisheries to use sorting grid to avoid catching undersized fish. The one and only exception from this rule is within an area in the southwestern part of the Barents Sea during 1 January – 30 April where trawling without sorting grids is permitted to catch haddock.

Shrimp

The landings of northern shrimp (*Pandalus borealis*) from the Barents Sea have varied between 25,000 and 130,000 tonnes. Norwegian vessels take about 90% of the catches, while vessels from Russia and the EU account for the rest. About 3% of the Norwegian catches are caught by smaller vessels in fjords and coastal areas. Most of the shrimp trawlers do also have a license to fish groundfish. In 2008, 18 Norwegian trawlers fished for northern shrimp, and only three of these were trawlers without groundfish license. Norwegian and Russian vessels exploit the stock in the entire area, while vessels from other nations are restricted to the Svalbard (Spitsbergen archipelago) fishery zone. There is no TAC established for this stock. The fishery is partly regulated by effort control. Licenses are required for the Russian and Norwegian vessels. The fishing activity of these license holders are constrained only by bycatch regulations, whereas the activity of third country fleets operating in the Svalbard (Spitsbergen archipelago) zone is also restricted by the number of effective fishing days and the number of vessels by country. The minimum stretched mesh size is 35 mm. Other species than shrimp are protected by mandatory sorting grids (Nordmore grid) and by temporary closing areas where excessive bycatch of juvenile cod, haddock, Greenland halibut, redfish or shrimp <15 mm length (CL) is registered. The shrimp trawlers use single, double or triple trawl.

Red King Crab

In 2002 both Russia and Norway started commercial harvesting of the red king crab in the Barents Sea. In both countries, this is a trap fishery which is regulated by quotas and fishing season. In Russia, 30 vessels have licence to fish red king crab. The fishery of female and undersized king crab is forbidden, while in Norway in all regulated fishing areas a small part of the quota may consist of females.

In Norway, the main fishing field is within the big fjords and along the coast of East-Finnmark. The commercial fishery for red king crab has now become a substantial fishery including a total of 400 Norwegian vessels. Inside 12 nautical miles off East-Finnmark (east of 26°E), only vessels less than 21 meters with a licence are allowed to participate, and the fishery is regulated by vessel quotas. The quota season in the Norwegian regulated area is from 1 April to 31 March. Legal size for the crabs is 13.7 cm carapax length and above.

Outside this area, except in the Grey Zone, all vessels are allowed to catch red king crab (no quota or gear limitations).

In Russia, the main fishing area for red king crab is the Murman Shallow (7) and the Eastern coastal area (14) (see Figure 2.5.3.). The fishing season in Russia is from 1 September to 15 February. Legal size for the male crabs is 15 cm carapax width and above.

Minke whale

Minke whales in the Northeast Atlantic are commercially exploited by Norway. The management of this species is based on application of the Revised Management Procedure (RMP) developed by the Scientific Committee of the International Whaling Commission. The total quota for 2009 is 885 animals. A licence is required for vessels to hunt minke whales. In 2008, 27 vessels (average vessel length of 22.4 meter) participated in the hunting. The hunt is conducted by harpoon grenades, and detailed prescriptions exist on how the hunt should be conducted and the weapons and ammunition used and secured.

Harp seals

No Norwegian vessel participated in the harp seal hunt in the East Ice (White Sea) in 2008. In the West Ice (Greenland Sea) one vessel did participate, also catching hooded seals.

Russia has an annual harp seal hunt in the White Sea during moulting time. The total Russian harp seal catch in 2008 was 13 331 animals. All of these were pups, i.e. age less than 1 year. The Russian hunting method has changed in recent years from mainly using helicopters to ice-going mother vessels with smaller hunting vessels. The total catch has in recent years been far below the recommended quota - in the West Ice only 3%, and in the East Ice only 7% of the recommended.

2.5.2 Pollution

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The Barents Sea is considered a cleaner environment than many other European seas, due to few local sources of pollution. However, for some types of pollutants there are well-known reasons to concern. Industries on the Kola Peninsula emit a wide spectrum of pollutants to the marine environment. The Barents Sea is influenced by pollution with origin outside the area which is transported into the area by ocean currents, ice drift or by the atmosphere. The long-range transport of contaminants is the most widespread source of pollution to the Barents Sea. The increasing oil and gas exploration activity and the transportation of oil along the coast of the Barents Sea are other potential sources of contamination to the area.

This chapter defines words related to pollution and identifies sources of pollution to the Barents Sea. Levels of contaminants in the environment are discussed in chapter 4.4.2. and impact on the ecosystem is discussed in chapter 2.6.3.

2.5.2.1 Definition of pollution

In this report the term pollution refers to elevated levels (above natural background levels for naturally occurring substances and levels above zero for man-made synthetic substances) of oil components/hydrocarbons, radioactive substances and environmentally hazardous substances. In addition, noise (see chapter 2.5.2), marine litter and ocean acidification are included.

Environmentally hazardous substances are those substances that may be dangerous to the environment. Their properties vary: they may be acutely toxic, corrosive, irritating to skin, sensitizing and explosive. Environmentally hazardous substance are not readily biodegradable and are bioaccumulative (accumulate in food chains and in the human body) and may cause damage to the environment even in low concentrations. They are categorised as ecological toxins. The most hazardous substances that are found in the Barents Sea environment are persistent organic compounds (POPs) such as polychlorinated biphenyls (PCBs), alkyl phenols and heavy metals like mercury (Hg) and cadmium (Cd).

Radioactive substances emit ionising radiation. Radiological toxicity (harmfulness to living organisms) varies widely from one substance to another depending on how readily they are absorbed by living organisms, the type of radiation they emit and its intensity. Radioactive substances are unstable and decay over time. Half-life is used as a measure of how long-lived a radioactive substance is, and can vary from only a few seconds to several hundred thousand years. The most environmentally hazardous radioactive substances that can be found in the Barents Sea area are anthropogenic ^{99}Tc *(technetium)*, ^{137}Cs (caesium), ^{90}Sr (strontium), ^{241}Am (americium) and plutonium isotopes ($^{239+240}$Pu) as well as the naturally occurring radionuclides ^{226}Ra (radium), ^{228}Ra ^{210}Pb (lead) and ^{210}Po (polonium).

Pollution caused by discharges of oil or other hydrocarbons is measured as total level of hydrocarbons (THC) and levels of polyaromatic hydrocarbons (PAH). These are both used as indicators for oil pollution. PAH can however originate both from natural (e.g erosion of coal-bearing bedrock, possible leakage of oil and gas from the seabed) and human made (e.g offshore industry and wood-burning) sources.

Naturally occurring substances do also contribute to the contamination of the Barents Sea. In addition to hydrocarbons, such substances include radioactive substances and heavy metals such as arsenic and nickel, which seep out of the sea-floor sediments. It is important to know the background level of these substances to enable realistic estimates of the level of human impacts and the effect of these.

Ocean acidification is a decrease in the pH in the oceans caused by uptake of anthropogenic carbon dioxide (CO_2) from the atmosphere. When carbon dioxide is absorbed by the oceans it reacts with seawater to form carbonic acid. The absorption of CO_2 is generally faster in colder waters such as the Barents Sea. Acidification can profoundly affect phytoplankton (coccolithophores), corals, molluscs, echinoderms and crustaceans, but recent research also indicates that eggs and larvae of fish may be endangered. For more information, see chapter 4.6.2 and 5.2.3.3.

2.5.2.2 Sources of pollution

Oil and gas
Discharges and emissions from oil and gas activities mainly influence the levels of hydrocarbons, some heavy metals and radioactive substances in nearby water, sediment or biota and emission of greenhouse gasses to air (emmission and discharges are given in chapter 2.5.3.4). Oil and gas activity in the Barents Sea has so far been limited. However oil and gas fields have been discovered in both the Russian and Norwegian part of the Barents Sea and both countries have plans for increased activities on their continental shelfs in the years to come (see 4.4.3.1).

Unexploited oil and gas reservoirs may also influence the ecosystem due to natural seepages of hydrocarbones. Some faults dissect the entire sediment level and are fixed at the bottom of the sea as relatively small siphons (up to 1 m in width and a few meters deep). These siphons are sources of local and temporary anomalies in the levels of heavy metals and hydrocarbons. They have been observed during the monitoring efforts near the Shtokman and Fedynsky fields as well as in the bottom waters and bottom sediments.

Maritime transport and fisheries
Maritime transport and fishing vessels may influence the environment negatively through operational discharges to sea and air, illegal discharges, waste (marine litter), introduction of alien species via ballast water and hulls and noise (see chapter 2.5.3.).

Ships contribute to emission of substances like CO_2, NO_x, SOx and PAH to the air and discharges of oil containing waste water to the sea. The knowledge about the exact size of the illegal discharges from ships to water in the area is limited.

Marine litter
Marine litter is found throughout the marine environment (seabed, water column and coastlines) and poses a risk to marine animals trough ingestion and entanglement. The main sources of marine litter are fishing (including abandoned and lost fishing gear), shipping and tourism. The extent of the problem in the Barents Sea area is unknown. Status for marine litter is given in chapter 4.4.2.3.

Radioactive substances
There are several local sources of radioactive substances in the Barents Sea area which poses a potential threat to the marine environment. Among these are radioactive waste containers dumped in the Barents and Kara Seas by the former Soviet Union (FSU) and sunken

submarines such as the Komsomolets in the Norwegian Sea and the K-159 in the Barents Sea (NRPA, 2006a; 2007b). Underwater and surface nuclear tests on Novaya Zemlya between 1955 and 1962 have resulted in local areas with high levels of radionuclides in the sediments.

Industrial activities, such as mining and oil production may change the distribution of naturally occurring radionuclides in the marine environment. From offshore oil production some volumes of produced water containing dissolved 226Ra and 228Ra can be discharged into the sea, but this will be small volumes because of the zero discharge requirements in the Barents Sea. Additionally, the possible use of Floating Nuclear Power Plants (FNPP) in oil and gas extraction in the Russian Arctic would increase the potential risk of radioactive pollution in the region (see also chapter 5.2.3.2). The primary groups of concern from a pollution point of view are the fission products (e.g. Cs, Sr isotopes) and transuranics (e.g. Pu, Np isotopes). Aside from risks associated with FNPP's themselves, there is further potential for pollution arising from supporting shore based facilities designed for the purpose of refueling, waste handling, decommissioning and other activities (NRPA, 2008c). Other sources of radioactive substances are mentioned under the relevant subtitles further in this chapter.

Transport of contaminants into the Barents Sea

The main sources of contaminants in the Barents Sea are those from outside the area and that are transported into the area.

Selected anthropogenic pollutants, including POPs, trace metals and radionuclides are transported via different pathways (mostly a combination of atmosphere, ocean currents, ice drift and rivers) into the Arctic and the Barents Sea (see Figure 2.5.9) Contaminants can later be redistributed within the region by a combination of the same transport pathways.

Atmospheric transport is the most rapid route for POPs (e.g PCBs, brominated flame retardants (BFR), PFC and heavy metals, incl. e.g mercury (Hg). Under favourable meteorological conditions, rapid air transport of contaminants can take place in a few days or weeks from the source region (e.g Europe, North America and Asia) into the Arctic (AMAP 2004). Contaminants are transported as gases, aerosols or they are absorbed by particles in the air, depending on the properties (vapour pressure, solubility etc.) of the contaminants.

Riverine inputs from larger rivers may be an important source of contaminants to the area. Particles transported to the coast by large Russian Arctic rivers like Yenisei and Ob during the melting period are contaminated with pollutants originating from industrial areas. As a result of various physical processes, particles, that may contain large amounts of contaminants, are incorporated in costal ice in the Kara Sea. These ice-bound particles may be transported into the Barents Sea and released in the main ice melting areas east of Svalbard (AMAP 2004).

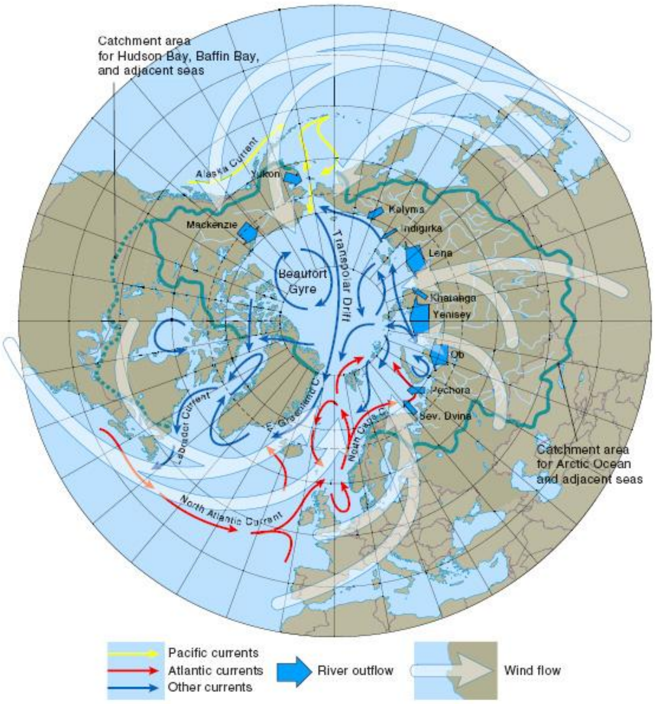

Figure 2 .5.9. Routes of transfer for persistent organic pollutants (POPs). Routes of transport of pollutants in the arctic includes atmospheric transfer routes, ocean currents, riverine output and transpolar ice drifting. (Source: AMAP 2004).

The transport via sea currents is a slow process and may take years, but may be important for transporting contaminants. Ocean currents, particularly the Norwegian coastal current, transport contaminants into the Barents Sea. This is especially noticeable for radioactive contaminants (^{137}Cs, $^{239+240}Pu$, ^{241}Am and ^{99}Tc) resulting from discharges from European nuclear reprocessing facilities in the Irish Sea and English Channel. Fallout from the Chernobyl Accident (1986) in outflowing Baltic water is also transported by ocean currents to the Barents Sea (e.g. Aure et al., 1998; NRPA, 2007; Matishov, 2001). Fallout from atmospheric nuclear weapons tests (1950-1980) and the Chernobyl accident can still be found in the Arctic marine environment.

Secondary sources of pollution

Secondary contamination is the release of pollution, which already is in the environment as a result of previous emission. This is e.g. fallout of aerosol particles from ice and snow into the sea water, input of chemical components from the bottom sediments as a result of geochemical processes in the “sea bottom-water” border region and formation of new chemical compounds within the water column from simpler components. Contamination due to water exchange in the river mouth where the industrial areas/human settlements are upstream can also be considered as secondary.

Pollution from onshore and near-shore sources

There are relatively few large sources of on-shore or near sources to pollution in the Norwegian part of the Barents Sea. There are however several small-scale discharges from many different sources such as landfills, fish farms, contaminated sites and small enterprises which may have the overall effect of raising pollution levels in near-shore waters. In many harbours where there are or have been shipyards or boat-builders’ yards, the sediments are polluted by tributyl tin (TBT) and tar. PCBs have also been found in some areas.

In some coastal areas in the Russian part of the Barents Sea area, local sources of pollution are considered to be considerable. An example is the municipal and industrial waste water in Murmansk which is discharged practically without any treatment into the sea. The coastal areas, and particularly the bottom sediments, are therefore not just contaminated, but have locally altered the physical properties, and also represent a source of secondary pollution to the environment.

The multiple Russian naval bases with nuclear submarines are a major source of environmental pollution. This includes leakage of radioactive substances from radioactive wastes stored in shore facilities (e.g. from Andreev bay), the use of support vessels to store radioactive waste (e.g. the Lepse), diesel and waste water discharge, pollution from special painting used on the ships and waste water from the communities connected to the naval bases. In the areas of tactical exercises there is a large amount of metal and, at times, highly toxic liquids that end up on the sea bottom. There is also a huge impact on the ecosystem from semi destroyed and sunken ships that often contain large amounts of fuel.

2.5.3 Oil and gas activities

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2.5.3.1 Historic development

Seismic surveys

The seismic surveys in the Russian part of the Barents Sea began in late 1960s. The process that was started consisted of 4 stages:

1. until 1973: the first reconnaissance transsections were done in the southern part of Pechora sea shelf,
2. 1972 -1978: “Sevmorgeologia” conducted research on the entire southern side of the Barents Sea shelf, including Yuzhno-Barents (southern Barents) depression.
3. 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. started in 1995. Focus on the northern parts of the Barents Sea shelf. The result was a completion of a regional stage of In 1979-1980, three specialised organisations were established in Murmansk – Arktikmorneftegazrazvedka (AMNGR) for exploration drilling and oil production; Sevmorneftegeofizika (SMNG) for seismic research; and Arctic Marine Engineering-Geological expedition (AMIGE) for complex geotechnical investigations.

SMNG completed over 400 000 km of seismic profiles 2D and 600 km2 - 3D; identified 178 structures and prepared 34 of them for exploration drilling. AMIGE bored 1600 geotechnical wells and static penetration of 52 000 metres in total.

Upon completion of seismic works in the Barents Sea, the density of seismic profiles of the shelf has become 0.31 km/km2. This density allowed to find 11 hydrocarbon fields, 4 - oil, 1 – oil/gas condensate, 3 – gas condensate, 3 – gas (Figure 2.5.10). To confirm the size of the deposits, AMNGR ran 160 000 metres of deep drilling and completed 51 exploratory wells.

Seismic data acquisition on the Norwegian shelf is divided into several categories: Seismic surveys performed by the authorities, commercial seismic and scientific data gathering. Ever since 1969 the Norwegian authorities have acquired seismic data in unopened areas in the Norwegian Sea and the Barents Sea. The seismic survey that has been done does also include the area around Svalbard. Up until 2001, the purchases of the Norwegian Petroleum Directorate's seismic data sets in the Barents Sea South have been mandatory for companies that wish to acquire other data in the same areas. This requirement has been discontinued in accordance with Storting White Paper No. 39 (1999-2000).

In the period 2007-2009 the Norwegian Petroleum Directorate performed regional 2D and 3D seismic surveys in the area Nordland VII and a limited area in Troms II as a follow up to the integrated management plan.

There is a further differentiation between company-owned seismic, license-owned seismic and marketable seismic. What all these categories have in common is that an exploration permit must be obtained from the Norwegian Petroleum Directorate. This data is reported to the authorities in accordance with the 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.

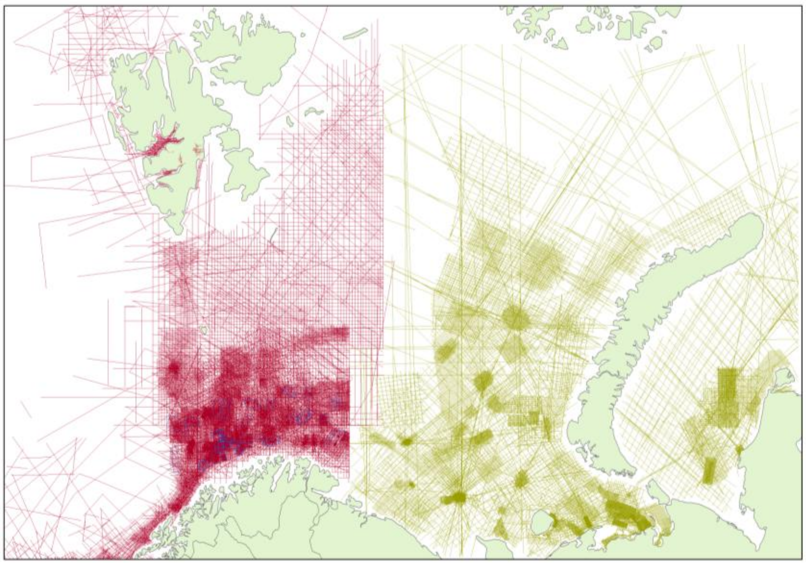

Figure 2.5.10. Map reflecting the seismic activity that has been carried out in the Barents Sea (source: the Norwegian Petroleum Directorate and “Official report Sevmorgeo for Ministry of Natural Resources "Cadastre of the Russian offshore zone", 2007”).

Exploration and appraisal wells

There have been petroleum activities in the Norwegian part of the Barents Sea since 1980, and the first discovery, 7120/8-1 Askeladd, was discovered the following year. This discovery is now a part of the Snøhvit development. 81 exploration wells have been drilled up to the end of 2008, and two main discoveries have been made, Snøhvit and Goliat.

Appraisal wells have been drilled in the Russian part of the Barents and Pechora seas since 1970s. 51 exploration wells have been completed by AMNGR, among them 33 – in the Barents Sea at sea.

2.5.3.2 Currents status of petroleum activities

Currently, there are no production oil/gas platforms on the Russian side of the Barents Sea. On the Norwegian part there is one field in production (Snøhvit) and one field in the planning-phase (Goliat) (Figure 2.5.11).

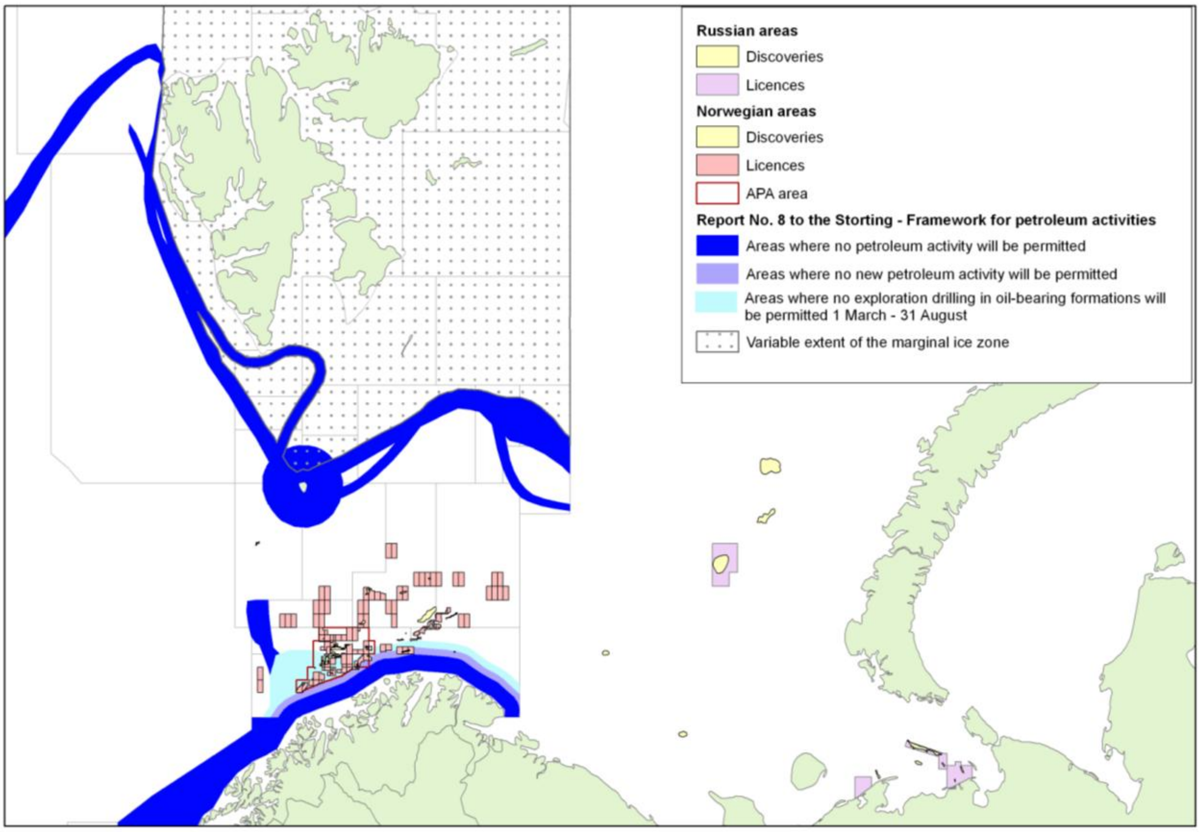

Figure 2.5.11. Map reflecting current status of petroleum activities in the Barents sea (source: the Norwegian Petroleum Directorate and Official report Sevmorgeo for Ministry of Natural Resources "Cadastre of the Russian offshore zone", 2007.

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 CO2 injection well. So far, nine production well and one CO2 injection well has been completed. Snøhvit is 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, and has produced approximately 3 million Sm3 in oil equivalents in 2008.

The reception facility at Melkøya outside Hammerfest receives the unprocessed well stream from Snøhvit. Gas condensate, water and CO2 are separated before the natural gas is being cooled down to liquid form (LNG) and stored in huge tanks. The gas is transported to the buyers in specially built tankers. CO2 is transported back to the field in a separate pipeline, and is injected in a deep formation under the producing reservoir.

Goliat

Goliat is located 50 km southeast of Snøhvit, only 70 km from the coast of Norway, and is a field in the developing phase. The field will be developed with a floating production and storage facility with subsea wells. Oil will be processed at the installation and transported by ship. The plan for the associated gas is to inject it into the reservoir for pressure support, Production of the gas will be evaluated at a later stage. The plan is that production drilling will start in 2011, and that field will come on stream in late 2013. The recoverable resources in Goliat are approximately 28 million Sm3 oil and approx. 7,5 billion Sm3 of gas.

Prirazlomnoye oil field

In the Russian part of the Barents Sea the oil production will start at Prirazlomnoye oil field. Prirazlomnoye oil field is one of the largest among the proven oil reserves in the Russian western Arctic shelf. Discovered in 1989, the Prirazlomnoye field is located in the Pechora Sea, about 60 km north of the Nenets Autonomous Region coast. The sea depth is 19 metres. According to adjusted production plans by Gazprom, commercial production will start in 2011. Initial geological oil reserves (C1+C2) of the field are estimated as 231.1 million tons (total geologically discovered oil reserves), and cumulative production should amount 76 million tons for the planned operation period of 23 years.

The largest among discovered oil fields in the Pechora Sea, Dolginskoye, with proven reserves of 235 million tons of oil is located north of Prirazlomnoye. Up to 2010 Gazflot plans to drill 7 new exploration wells at Dolginskoye and get the first oil in 2015.

Oil production is planned on three more licensed sites in the Pechora Sea – Medynsko-Varandeyskiy area, Kolokolmorskiy and Pomorskiy blocks. The licenses are owned by Arktikshelfneftegaz, and the oil fields can be put in operation after 2010. The estimated recoverable hydrocarbon reserves of these three blocks may exceed 300 million tons of oil.

Shtokman field

The Russian Arctic shelf biggest hope is the Shtokman gas field in the Barents Sea. This field is located in the central part of the Russian sector of the Barents Sea shelf, about 600 km northeast of the city of Murmansk at local sea depths of 320-340 metres. In 2008, Vyborg Shipbuilding Plant started construction of two semi-submersible drilling rigs for Gazflot, a subsidiary of Gazprom, to drill production wells on the Shtokman field. Shtokman gas and condensate field was discovered in 1988. The plan is to get the first production gas at Shtokman in 2013, and the first LNG in 2014.

There is an increasing interest for exploration in the Barents Sea. The development of Snøhvit has shifted attention towards the area once more, as have new discoveries of oil and gas resources in the Hammerfest Basin and the previously little investigated eastern part of the Barents Sea. The large discoveries in the Russian part of the Barents Sea have also contributed to the increased interest for the Norwegian part. The Barents Sea is in general little investigated, even though it is assumed that the Arctic contains a substantial part of the world's undiscovered petroleum resources.

2.5.3.3 Potential petroleum resources

The proven petroleum resources in the Norwegian part of the Barents Sea are 325 million Sm3 oil equivalents and of these 3 million Sm3 oil equivalents have been produced. There has been an increase in the resource estimate the last year due to 4 new discoveries. The estimates for undiscovered resources in the Norwegian Barents Sea is just above 1 bill Sm^3 o.e.

In 2008, Ministry of Economic Development of Russia elaborated the “Concept of the State programme for exploration and development of the continental shelf of Russia”. According to the “passive” scenario the maximum yearly oil production on the shelf will be 30 million tons in the period from 2010 to 2030; and by the “active” scenario oil production, with development of discovered and prospected oil fields on the shelf, may reach the level of 90 millions tons a year in 2020.

2.5.3.4 Emission, operational and accidental discharges

Operational discharges to the sea

The main discharges into the sea from the oil and gas activities come from drilling and well operations, and from the production phase.

Drilling

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

Discharges of oil based drilling fluids or cuttings drilled with oil based drilling fluids have been prohibited from Norwegian drilling operations since 1992 due to the proven harmfulness of the mineral oil. Used drilling fluids and cuttings is now 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. Discharges of used drilling fluids and cuttings drilled with water based drilling fluids are permitted on most parts of the Norwegian Continental Shelf. In the Barents Sea, however the Norwegian authorities will normally not accept discharges of water based drill fluids or cuttings except from the top part of the well, where collecting the cuttings is difficult due to lack of riser (pipe connecting the well head to the drilling rig).

Discharges of cuttings from the top part of the well requires that no harmful or hazardous chemicals have been added to the drilling fluids, and that there are no known especially vulnerable marine spices or resources in the area.

Discharges of cuttings will lead to a certain degree of smothering of the sea bed. This has been shown to have only very limited effect on the sea bed communities, and the amount of rocks, pebbles, sand and clay deposited is often less than what is deposited as a result of natural movement of solids caused by under water currents along the sea bed. However, special care has to be taken in area with proved or expected occurrence of cold water corals.

Production

A source of discharge to sea from production phase is produced water, although discharge of produced water from normal operation is prohibited in the Norwegian part of the Barents Sea. This fluid is water produced from the wells together with the oil, condensate and gas, and will contain dispersed oil (small oil droplets), dissolved oil and naturally occurring chemicals components like heavy metals (for example lead and chromium) and radionuclides (226Ra and 228Ra). Some organic compounds will also be present. These will be, carboxylic acids, volatile fatty acids (acetic acid), BTX (benzene, toluene and xylene), phenols, PAH (polyaromatic hydrocarbons) and alkyl phenols.

In the early years of production, the amounts of water usually are low, but the water/oil ratio will increase with time (a water content of 80 – 95 % is not uncommon from some old fields in the North Sea). In most parts of the Norwegian waters produced water is injected into the formation or discharged into the sea if the content of dispersed oil is low (varies from one field to another, with 30 mg oil per litre of water as an absolute maximum level permitted by SFT, while oil content down to 5 mg/l is achieved at several installations). Expected requirements in the Barents region is that produced water shall be reinjected into the formation, with only maximum 5 % being discharged after cleaning treatment. Other types of fluids that may occur are drainage water, cooling water, household water and sewage water.
Different kinds of chemicals are used during drilling and production. The effects of the discharges of these are evaluated based on their intrinsic properties (potential for accumulation in tissue, biodegradation rate and acute toxicity).

Solid waste generated offshore during drilling and production activities, including installation of platform and equipment, maintenance etc, have to be taken to shore for treatment or disposal. As a part of decommissioning after closing down the production, the operators are not allowed to leave any debris or surplus material from drilling rigs, sub sea well head installations, fixed installations or installation of pipelines.

Emissions to air

Offshore oil and gas activities also contribute to air emissions, of for example by emission of CO2, NOx non-methane volatile organic compounds (NMVOC), methane, and SO2. These arise from energy production, flaring gas from well testing, flaring associated gas during oil production, and from venting (release of unburned gas from pipes and valves in the processes etc during normal operations). Noise from surveys, drilling and production may also have an effect on the environment.

Accidental discharge

During drilling and production activities, there is always a risk of accidental discharges. Most accidental discharges of oil or chemicals are small, and caused by overfilling of tanks, leakages from pipes or transfer lines, loose fittings or couplings, valves that are open when they should be closed, and in a few cases ruptures of pipelines.

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

Other large technical failures like breakage of pipelines, refilling lines etc may also cause large spills similar to the Statfjord A spill in the North Sea in December 2007.

2.5.4 Maritime transport

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2.5.4.1 Shipping activity

In numbers, fishery activities currently account for most of the shipping traffic. The cruise industry contributes to annual and seasonal variations. A large share of the goods to, as well as within, Norway's three northernmost counties is transported by ship. For Russia, sea shipping is of great importance connecting territories with each other and playing a vital role in external economic activities. The role of sea shipping remains essential in supporting the life of coastal communities in Russia.

The biggest liquid commodity carried by ships are oil, crude and products, being carried from northern Russia and Northern Norway to destinations in Europe and some to Northern America, by LPG (Liquified Petroleum Gases) carriers from Melkøya and product tankers to Norwegian and Russian oil depots. In 2008, eight terminals in the Russian Arctic from Ob Bay in Kara Sea to Kola Bay in the Barents Sea received crude, oil products and gas condensate by production pipelines, river tankers and railways over land and shipped the load by sea for export. A number of small sea tankers went from those terminals all the way to European and American destinations, but most of the petroleum load was transhipped in the ice free areas of the Barents Sea, at FSO in the Kola Bay or STS (ship to ship transfer) terminals in the Northern Norway. According to Russian port administrations, customs and terminal operators, did the eight terminal in the Russian arctic offloaded about 10 million tons of liquid hydrocarbons for export annually (measurement for the four last year) (Figure 2.5.12.)

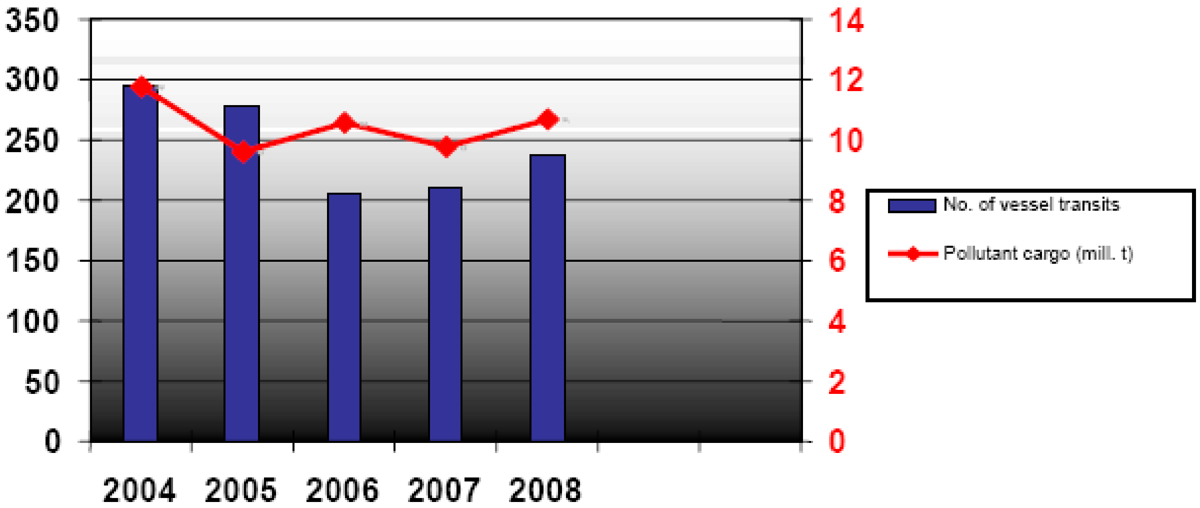

Figure 2.5.12. Number of vessel transits with noxious cargo (with the potential to pollute if discharged to the environment) through the Norwegian part of the Barents Sea in the years 2004 - 2008. (Report from the Norwegian Forum on Environmental Risk in the Barents Sea Source: Armed Forces Norway)

A new terminal: Varandey with a capacity of 12.5 million ton/year was set in operation in June 2008. In January 2009 it exported 550 thousand tons of crude. In 2009 it is expected that about 7 million tons of Timano-Pechora oil will be transported by ship for export. It is predicted, that Varandey and other terminals will ship about 15 million tons of Russian crude and petroleum products for export via the Barents Sea in 2009.

In addition to Russian oil and petroleum products transported by the Barents Sea, in 2007 Snøhvit gas field and LNG (Liquified Natural Gas) plant on Melkøya started to produce and ship gas condensate, LNG and LPG. 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. The export prognoses for 2009-2013 are to offload annually 4.3 million tons of LNG, 460 000 tons of LPG, and 220 000 tons of condensate.

Recent analyses of the tanker traffic show that the type of cargo has been changing. The volume of transported crude oil has increased by 52% and gas condensate by 25% since 2007. However, there is an element of uncertainty in these data, as the control of unknown shipments was improved from 2007 to 2008. It has been claimed that the increase in crude oil shipments indicates that Russia is routing more oil to the north (Bambulyak, A. and Frantzen, B. (2009)).

According to Russian port administrations and terminal operators, in 2008 the share of crude oil in the exported liquid hydrocarbon cargo from the Russian Barents was 38%, gas condensate – 20%, naphtha – 26%, heavy fuel oil – 5%, and other oil products – 11%. The increase in crude oil shipments in 2008 happened as a result of start up production at a big

Yuzhno Khylchuyu oil field in northern Timano-Pechora and the new Varandey terminal set in operation. At the same time, decline in heavy fuel oil export happened due to internal challenges at two terminals in the Kola Bay. In the future, the share of crude in Russian exports through the Barents Sea will be increased thanks to Varandey operation; at the same time we may see decrease in refined products delivered to the ports of Vitino and Murmansk by railway when Ust'-Luga port in the Baltic is put on stream.

Ship to ship transfer (STS)

The first STS terminal was established in the Kola Bay of the Barents Sea back in 2002. For the period from 2002 to 2004, five more STS and FSO (Floating Storage and Offloading vessel) terminals were established in the Ob Bay of the Kara Sea, the Onega Bay of the White Sea, and the Kola Bay. STS terminal in the Onega Bay transhipped heavy fuel oil in 2003 and was closed after the accidental oil spill. One STS terminal in the Kola Bay worked for three months only in 2004 and was closed. STS in the Ob Bay tranship crude from Western Siberia during summer and send to FSO Belokamenka in the Kola Bay. Belokamenka also receives Timano-Pechora crude from the terminals in Varandey and Arkhangelsk. Two tankers are also used as FSO for heavy fuel oil at two by-port terminals in the Kola Bay.

In Norwegian part of the Barents Sea STS transfer of petroleum products has been carried out since 2002 at two sites in Finnmark, Bøkfjorden and Sarnesfjorden. Gas condensate is the main product being transhipped on these locations today, but there are pending applications for STS transfer of other products, such as crude oil, petrol and naphtha.

As long as tankers sail along the coast, there are established shipping lanes, but the traffic to and from the STS transfer sites in the fjords will go close to land. Transfers in the fjords, either at dockside or under anchor, are considered to be Norwegian industrial activity, and is thus under control of the Norwegian Pollution Control Authority (SFT) and the Norwegian Coastal Administration (Kystverket). STS transfers outside of Norwegian territorial waters, as long as the ships are under their own engine power, are subject to the provisions of the MARPOL Convention, Annex I.

Discharges from maritime transport

The day-to-day impacts of shipping on the environment are caused by ordinary operational discharges. Discharges of sludge and oily bilge water from machinery spaces and discharges of oil and oily mixtures from the cargo area (slops) are regulated internationally by MARPOL 73/78 (International Convention for the Prevention of Pollution from Ships). The Convention permits a certain level of discharges of oily bilge water and oily mixtures from tank washings. However, all ships are required to have segregated ballast tanks by 2010, and this will almost eliminate discharges of oily ballast water. Oil slicks on the sea with unidentified source are reported every year, and most of these are assumed to come from illegal discharges from ships.

Introduction of alien species

Maritime transports to Norway and tanker traffic to Northwest Russia are currently dominated by vessels from large European ports. These tend largely to call at ports in the same biogeographical area, and take ballast water from areas where the flora and fauna is similar to that in Norwegian waters. However, there is a risk of the further spread of alien species that are established in these waters to the Barents Sea, either in ballast water or attached to ships' hulls. Other categories of vessels such as general cargo and container ships operate in a global market. A good many of these are likely to come from foreign ports in other biogeographical zones, but where physical and chemical conditions are similar to those in Barents Sea. In future, there may be a particularly high level of risk associated with use of the Northwest Passage combined with failure to treat ballast water.

2.5.5 Other human activities

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2.5.5.1 Tourism

Tourism is one of the largest and steadily growing economic sectors world-wide. Tourism is a recent development in the arctic. Visits to the far north have increased considerable during the last 15 years with up to nearly one million tourists annually. One of the most visited arctic areas in the world is Svalbard. In 2005 approximately 70 000 tourists visited Svalbard and during the last ten years the amount of tourists has been doubling on Svalbard. In recent years also an intensification of cruise tourism (Table 2.5.3) is expected to be seen on Svalbard.

Table 2.5.3 Numbers of overseas cruise ship on Svalbard and number of passengers onboard. Source: The governor of Svalbard.

	Number of cruise ships	Number of passengers
1997	24	15437
1998	21	17463
1999	31	17763
2000	29	16404
2001	25	20069
2002	22	16892
2003	28	19736
2004	28	21206
2005	34	29224
2006	29	28787
2007	30	32781
2008	29	29587

The Russian President Dmitry Medvedev has announced during the Safety Council that an increase in the ecological tourism in the Arctic is an important direction for the Russian activities. Since 1989 tourist cruises to the North Pole have been arranged on Russian nuclear icebreakers. The first tour was done by Sibir icebreaker back in 1989. From 1991 to 2008, Yamal icebreaker was the main nuclear cruise ship for the Arctic tourists, and in 2008 the world's largest and newest Russian nuclear icebreaker 50 Let Pobedy brought its first tourists to the North Pole. Altogether, nuclear icebreakers have made 64 trips with tourists to the North Pole, including two cruises conducted in summer 2009. Usually, the tours to the North Pole are arranged in the period from July to September, and last for 2 weeks, starting and ending in Murmansk and visiting Frantz Joseph Land on the way to the Pole. In addition to trips to the North Pole with nuclear icebreakers, diesel icebreakers, like Kapitan Dranitsyn, have made 1-2 tours a year to Franz Joseph Land and nuclear icebreakers have also done cruises through the Northwest Passage. Icebreakers can have up to 100 tourists on board, and most of the tourists travelling to the North Pole are from the USA, Western Europe and Japan.

With establishment of the Russian Arctic national park on Northern Island of Novaya Zemlya (the Decree was signed by Russian Prime Minister in summer 2009) tourist activity in the area is expected to grow in nearest future.

2.5.5.2 Bioprospecting

Marine bioprospecting is defined as systematic search for interesting and unique genes, molecules and organisms from the marine environment with features that may be of value for commercial development. The high biodiversity of the oceans represents a correspondingly rich source of chemical diversity. Marine natural products identified by bioprospecting could have potential as new drugs, industrial enzymes, anti-freeze proteins, nutraceuticals and dietary supplements as well as ingredients in cosmetics. Other results from marine bioprospecting could be new technology for bioremediation and more efficient oil production. There is a growing scientific and commercial interest in the biotechnology potential of Arctic biodiversity, and researchers from several nations are currently engaged in research that could be characterised as bioprospecting.

2.5.5.3 Aquaculture

In Russia two companies, Russian Salmon (Russkiy Losos) and Gigante Pechenga has established four commercial fish farms in the Ambarnaya and Pechenga bays of the Barents Sea. They cultivate nearly a million salmons and produce more than 3000 tons of fish a year. The two firms plan to install another 14 net cages in the Pechenga area.

The aquaculture activities in Norway are spread onto 130 different locations around the coastline of Finnmark.

Atlantic salmon, rainbow trout and trout

In the county of Finnmark there are 83 licences for production of salmon. Each licence gives the right to keep 900 ton of fish at any time. After a period of consolidation the production are again increasing (Figure 2.5.13).

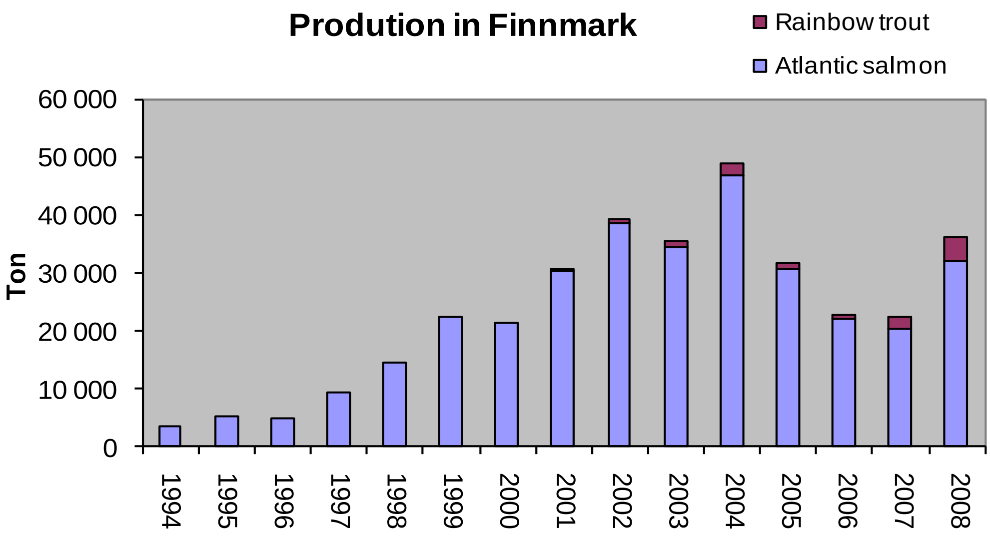

Figure 2.5.13. The figure shows the production of Rainbow trout (Oncorhynchus mykiss) and atlantic salmon (Salmo salar) in Finnmark (source: Directorate of Fisheries , Norway).

Other marine fish

There where 47 licences in January 2009 in Finnmark, most of them are cod licence. Each licence gives the right to keep 780 ton of fish at any time. Figure 2.5.14 shows the cod production in Finnmark Some of the farmers based the production on wild catch cod and others use artificially produced juveniles.

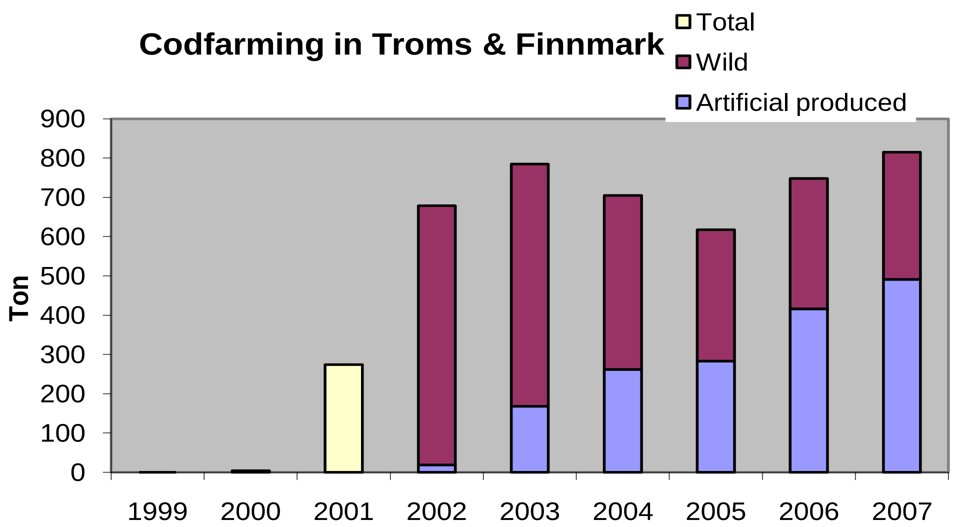

Figure 2.5.14. The figure shows the production of cod (sold) in Finnmark (source: source: Directorate of Fisheries , Norway).

Shellfish

Shellfish licence in Finnmark includes blue mussel, sea urchin and king crab. Blue mussel farmers are struggling with poisonous algae and have not been able to sell their shells (Figure 2.5.15).

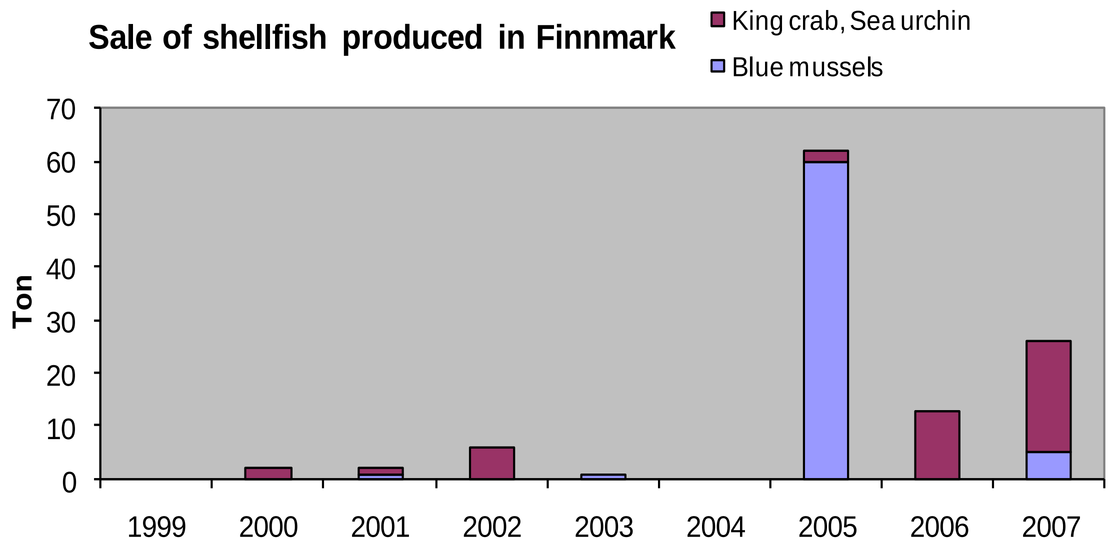

Figure 2.5.15. The sale of shellfish production in Finnmark (source: Directorate of Fisheries, Norway).

2.5.5.4 Nuclear icebreakers of the Russian Federation

According to ESIMO and CNIIMF, today, Russia has 7 nuclear icebreakers in operation built in the period from 1974 to 2007 (see table 2.5.4). All of them are state owned, managed by Atomflot (until 2008 been operated by Murmansk Shipping Company), having Murmansk as a port of registry, and working in the Arctic seas.

Table 2.5.4. Nuclear ice-breakers of the Russian Federation (Source: ESIMO).

Name	IMO number	Year built	GT	Power
Arktika	7429061	1974	20665	2x27500
Rossiya	8424240	1985	20680	2x27600
Sovetskiy Soyuz	8838582	1989	20646	2x27600
Taymyr	8417481	1989	20791	2x18400
Vaygach	8417493	1990	20791	2x18400
Yamal	9077549	1992	20646	2x27600
50 Let Pobedy	9152959	2007	23439	2x27600

2.6 Ecosystem interactions

To understand the overall dynamics of an ecosystem and the way it is affected by human activities, it is important to consider both the impact of natural environmental variations and multispecies interactions. This chapter therefore starts (2.6.1) with a description of effects from environmental variation on the biological groups described earlier in chapter 2.4. It then goes on to describe multipsecies interactions within and between these groups (2.6.2). Impact from the human activities described earlier (chapter 2.5) is the focus of the next subchapter (2.6.3). In the last subchapter (2.6.4) it is discussed how the different kinds of interactions and impact form the broad and overall general dynamics in the Barents Sea ecosystem.

2.6.1 Abiotic impact

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This subchapter describes effects of variation in the physical part of the ecosystem on biological groups. Such links are strong and important for the overall dynamics of the Barents Sea ecosystem. For example, variation in temperature has significant effects on reproduction and recruitment of several of the large fish stocks, and variation in ice cover may have considerable effects on primary productivity. It should be underlined that the aim of this subchapter is not to discuss the effect of long term human induced climate change. Rather, the focus is on effects of natural variation the physical environment. Effects of long-term climate change are discussed in chapter 4.6.

2.6.1.1 Phytoplankton and zooplankton

Distinctions in quantitative distribution, structure and rates of development of phyto- and zooplankton are connected with the temperature influence, related to ocean currents and the distribution of the ice and the ice edge. Many species of phytoplankton have a rather wide tolerance range for parameters such as temperature and salinity, and also adapt to different levels of light down to its very minimum. However, some of the species in the Barents Sea are connected to colder water or ice edges, with more specific demand in these parameters. For species with a more narrow tolerance in these parameters changes will have a strong effect on their distribution and abundance. Large changes in these parameters could result in changes in the overall phytoplankton community composition, changes that could be critical for some species and their predators. However, in most cases such changes might only have a negative effect on the specific species, whereas the overall structure of the phytoplankton could be unaltered since “new” species could take up there ecological role in the food web.

Variation in the climate, explicit as ice cover, could affect the annual primary production. Models of primary production indicate that years with higher temperature and higher inflow of warmer Atlantic water result in a higher annual primary production (new production) in the Barents Sea (Figure 2.6.1). The observed annual changes in the model primary production are explained by the percentage of ice free water masses. The annual average production becomes lower in those year when the ice is widespread and if the melting of the ice occur later in the season. Even thought production in the ice edge and polar front could by high (measured as chlorophyll a) it only covers a narrow area along the edge and occurs in a short time period, and the portion to the total production is therefore low, except for years when the ice is widespread.

For zooplankton, variation in temperature, currents and ice distribution can have strong effect on individual species. The strongest effect of this is seen in the Arctic species Calanus glacialis, which is usually connected with cold Arctic water, unlike C. finmarchicus which is more related to the inflow of the Atlantic waters. Cold water also slows down the growth and maturation of copepods. Potential changes in the microzooplankton community are hard to evaluate as the knowledge of these groups and species from the region is very limited.

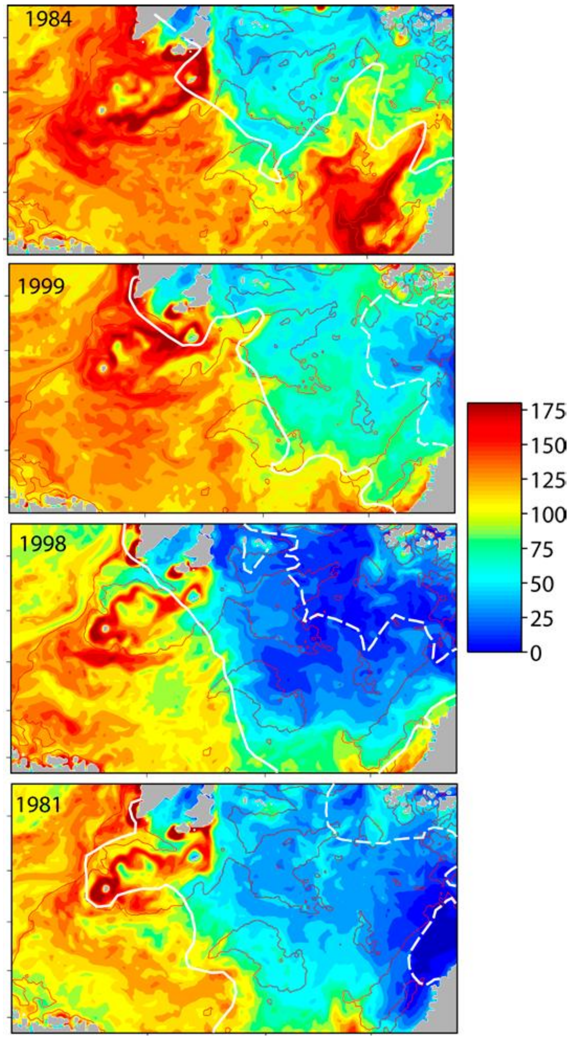

Figure 2.6.1. Modelled yearly primary productivity (g C m-2 y-1) in the Barents Sea for four selected years, two years with less sea ice (top panels) and two years with more sea ice (bottom panels). Sea ice boundaries are given for April (solid white line) and September (dotted white line).

2.6.1.2 Benthos, shellfish and squid

Boreal-arctic species dominate the biomass of benthos in the Barents Sea (as well as throughout the arctic shelf), and have an optimum temperature range lying within the long-term temperature mean of the region. According to this latter theory, any deviation from the long-term mean has a negative impact on boreal-arctic species reproduction, abundance, and biomass. Some studies suggest that the decline in total biomass of benthos from 1924-1935 to 1968-1979 (Antipova 1975b) is due to a change in faunal distribution during the cold period between the 1960s and 1980s (Figure 2.6.1; Bryazgin, 1973; Antipova, 1975b; Bochkov and Kudlo, 1973), while others invoke declining biomass of resident boreal-arctic species during the 1930s-1960 warm period (Galkin, 1987; Kiyko and Pogrebov, 1997a; Kiyko and Pogrebov, 1998).

One of the most consistent features found on Arctic continental shelves, including the Barents Sea, is the tight coupling between pelagic production and benthic abundance, biomass, and processes (e.g. Piepenburg, 2005, Renaud et al., 2008). Therefore, oceanographic factors influencing the spatial distribution of pelagic production (fronts, upwelling) will often be mirrored in distribution and biomass of benthic fauna (Grebmeier et al., 2006; Wassmann et al., 2006). One feature of the Barents Sea that has received some attention is the position of the Polar Front (i.e. the border between Atlantic and Arctic water masses). Due to enhanced sedimentation of fresh phytodetritus in this region (Carmack and Wassmann, 2006), infauna in this area generally has higher abundance and biomass, and different dominance patterns, than either north or south of the Front (Denisenko et al., 2003, Carroll et al., 2008). Where the Front becomes more diffuse to the east of the Barents Sea, however, this trend is somewhat reduced (Cochrane et al., 2009). Areas of strong bottom currents and presumed high resuspension/ advection of organic material (e.g. bank areas), suspension-feeding epifaunal organisms are found in high abundances, further indicating the dependence of benthic production on food input (Wassmann et al., 2006).

Whereas benthic stocks (abundance, biomass) reflect signals of delivery of pelagic production to the sea floor that are integrated over years to decades, respiration/remineralisation rates are determined by food delivery to the sediment surface on scales of days to a few weeks (Renaud et al., 2008). Abiotic processes influencing benthic rates, therefore, include those factors affecting phytoplankton production (see above), but also short-term events that affect water column stratification, and thus both mixing of nutrients and active downward transport of particulate material. These short-term processes include ice melt, wind/storm events, brine rejection during freeze-up, and tidal action.

2.6.1.3 Climate and fish

Climate variability affects fish in a variety of ways and throughout its life cycle. Sea temperature is the variable that has received the most attention from researchers in terms of its effects on both pelagic and demersal fish. Successful individual growth often occurs within a limited thermal range that differs among species and even between developmental stages within the same species. Generally, fish in colder waters tend to exhibit slower individual growth than those in warmer waters (Godø, 2003).

Faster growth results in reduced susceptibility to predation due to shorter durations during early development stages, thereby affecting mortality rates. Temperature also affects swimming speed and activity rate (Fuiman et al., 2005, 2006), which in turn affects both feeding success and anti-predator behaviour through changes in encounter rates with prey and predators, respectively. Temperature can affect gonadal development resulting in spawning times generally occurring earlier under warmer-than-normal conditions (Hutchings and Myers, 1994). The age-of-maturity in different stocks of Atlantic cod, including the Northeast Arctic cod, varies with temperature (Drinkwater, 2000) and is believed to be caused by faster growth rates for those cod stocks inhabiting warmer waters. Recruitment varies with the temperature experienced during the first years of life with higher recruitment generally occurring during periods of higher temperatures for both cod (Sætersdal and Loeng, 1987; Ellertsen et al., 1989; Ottersen and Sundby, 1995; Ottersen and Stenseth, 2001) and herring (Toresen and Østvedt, 2000). Earlier seasonal warming leads to earlier migratory movements, e.g. for capelin in the Barents Sea (Ozhigin and Luka, 1985, Tjelmeland, 1987). Persistent warming has resulted in northward expansion of several species in the Barents Sea, including Atlantic cod and Atlantic herring (Drinkwater, 2006) and capelin (Vilhjálmsson, 1997). In addition, Atlantic cod has been shown to favour more northern spawning during warm conditions and more southern under cold conditions (Sundby and Nakken, 2008).

Other abiotic factors than temperature affect fish. Dispersion of fish eggs and larvae from their spawning ground is considered a key aspect of recruitment success as currents may carry them into or away from favourable nursery areas. Numerical models are well suited for the study of transport of fish larvae, e.g. for Northeast Arctic cod (Vikebø et al., 2005). These studies indicate that where the larvae settle and recruitment success has a strong dependency on wind-dependent drift. Turbulence levels can also be important as these affect the contact rate between larval fish and their prey (Rothschild and Osborn, 1988), which in turn can affect their feeding rates (Sundby et al., 1994).

2.6.1.4 Marine mammals

Because marine mammals are large, homeothermic animals, they can cope with significant ranges of water and air temperatures. So, marine mammals residing in, and those that currently migrate seasonally into, the Barents Region are not likely to be directly physiologically challenged by the predicted increases in air and water temperatures. Physical changes in the marine environment are likely to have impacts first and foremost on the animals that depend on sea-ice (e.g. Kovacs and Lydersen, 2008; Kovacs et al., 2009).

Changes in the geographic extent of sea ice and in the seasonal period of coverage of the sea ice are likely to impact on the distribution and abundance of most, if not all ice-dependent marine mammal species in the Barents Region, including polar bears, ringed seals, bearded seals, harp and hooded seals, bowhead whales, narwhal and belugas. Polar bears depend on sea ice as a hunting platform for much of the year to access ice-dependent seals, which are their primary prey. The ice dependent seals depend on sea ice as a resting platform and a breeding substrate. The cetacean link is somewhat less direct, but, it is thought that the three resident arctic cetaceans feed on ice-associated prey and also benefit from sea-ice providing protection from predators, in particular killer whales. Sea ice coverage is likely to affect range expansions for pelagic marine mammal species that migrate into the region from temperate areas on a seasonal basis.

2.6.1.5 Seabirds

Physical variation in the Barents Sea is likely to affect seabirds both directly and indirectly. Direct influence works primarily through the effects of temperature, wind and precipitation during the breeding season, and through extreme weather outside the breeding season. Temperature and wind affect the birds' energy budget, and changes in these factors can impose great energy costs on the birds. Air temperature is partly responsible for determining the onset of breeding for several species. Severe precipitation during the breeding season may lead to increased chick mortality, and thus a reduction in breeding success, especially for species breeding in flat ground. Long-lasting autumn and winter storms may lead a great number of seabirds to stray off course, most of which succumb after a while. Extended periods with extreme weather can also prevent the birds' foraging activities, resulting in starvation. Seabirds dependent on sea ice may be affected directly by climate changes. Ivory gull *Pagophila eburnea*, for example, which is sea ice dependent through the entire annual cycle, is expected to change distribution, decrease in abundance or the species may disappear totally from the Barents Sea in the complete absence of sea ice in the summer season. However, the most important climatic effects are by far *indirect*, when sea temperature, ocean currents and wind directions affect the availability of the seabirds' prey.

2.6.2 Biotic interactions

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The organisms in the ecosystem are linked through ecological interactions to form a food web, which has several trophic levels: producers (plants) at the lowest trophic level, primary consumers feeding on the producers, secondary producers feeding on the primary consumers and so on up to the apex predators that do not have any predators feeding on them, except for young stages in some species and some species where adults may be killed by humans. Because energy transfer from each trophic level to the next (e.g. the producers to the primary consumers) is not 100% efficient (as a general rule of thumb, the efficiency is only 10%) the biomass and production is highest in the lowest trophic levels and lowest at the highest trophic level. Organisms at different trophic levels influence each other through predation, whereas organisms at the same trophic level influences influence each other through competition – since they feed on the same food sources. Predation and competition are important biotic interactions that determine the dynamics of abundance and spatial distribution of the species in the ecosystem. Other kind of interspecies interactions, such as parasitism and mutualism, may also influence population dynamics, but these effects are less known and studied.

2.6.2.1 Phytoplankton (and ice algae) - competition and main predators

In the Barents Sea, phytoplankton is the main primary producer sustaining the rest of the food web. Within the phytoplankton community there is a competition for light and dissolved nutrients. The phytoplankton species in the Barents Sea are either pelagic, or linked to the ice edge in a way similar to the ice algae. Phytoplankton blooms in spring and summer and attracts concentrations of intensively feeding secondary producers and their predators. The phytoplankton is both consumed by pelagic zooplankton and sink to the seafloor and sustain benthic feeders there. Arctic shelf systems, and the Barents Sea in particular, have been shown to exhibit a tight pelagic-benthic coupling, i.e. stocks and processes of benthic organisms seem to be highly dependent on food inputs from pelagic sources (e.g. Piepenburg, 1997, Renaud et al., 2008, Tamelander et al., 2008). Until recently it was unclear how important production from the ice algae was to either zooplankton or benthic systems. Recent studies, however, have shown that zooplankton actively graze on ice algae where they co-occur, and that ice algae can be critical to completion of zooplankton life-cycles (Søreide et al., 2008). In addition, rapidly sinking ice algae can be tracked to the seafloor (Morata and Renaud, 2008, Tamelander et al., 2008), where it is readily assimilated by both filter-feeding and surface deposit-feeding benthos (McMahon et al., 2006). Finally, correlative evidence also exists that further suggests the importance of direct input of ice algae and other phytoplankton, forming detritus for benthic communities. High density aggregations of benthic filter feeders are found on shallow banks of the Barents Sea in areas characterised by both high pelagic production and strong near-bottom currents (e.g. Wassmann et al., 2006).

2.6.2.2 Benthos, including shrimp and shellfish- competition, main prey and predators

Benthic invertebrates are diverse organisms both in terms of species richness, and feeding and way of life. They are often very habitat specific. Sessile benthic organisms are known to compete for space. Some benthic organisms are filter feeders, some feed on detritus and sediments and some are predators. Decapods are known predators of benthic bivalves, including scallops (Elner and Jamieson, 1979; Arsenault and Himmelman, 1996; Anisimova et al., 2005).

The diet of the red king crab, *Paralithodes camtschaticus* (Tilesius, 1815), has been studied in detail, since introduced predators might have particularly large impact on native communities (Elton, 1958; Lodge, 1993; Ross et al., 2003). Food appears to be the sole factor that could limit the increase in abundance of red king crabs within the Southern Barents Sea (Gerasimova, 1997). Stomach analyses from the invaded area show that the crab feeds on a diverse range of molluscs, echinoderms (sea urchins, sea stars, basket stars, holothurians), crabs and others crustaceans, worms (*Polychaeta* and *Sipunculida*), and fish (Jewett et al., 1989; Sundet et al., 2000; Anisimova and Manishin, 2003). Conspicuous native epibenthic species such as the commercial Iceland scallop *Chlamys islandica* O.F. Müller, 1776) are particularly exposed to risk of local extinction, and use the same depth range as red king crab. Russian long-term observations showed that on the average frequency of occurrence of fish eggs in the crab stomachs in spring was not higher than 6% and its percentage in the crab diet accounted for not more than 2%. In 2001, an investigation on king crab consumption of capelin eggs showed that the crab consumed 0.03% of the capelin egg spawning mass in Russian economical zone (Anisimova et al., 2005).

Shrimp (*Pandalus borealis*) is of great economic and ecological significance. Several species of fish and marine mammal prey on shrimp (Magnusson and Palsson, 1991a; Pedersen and Riget, 1993; Grundwald, 1998; Nilssen et al., 2000). Cod is considered an important predator on shrimp (Berenboim et al., 2001, Hvingel and Kingsley 2006 and references therein). Increase in shrimp stocks has been observed in Greenland and Canada following large declines in co-existing cod stocks, suggesting that cod may control shrimp abundance (Hvingel, 2006a). However, even though the estimates of annual shrimp consumption by cod (based on stomach samples) in the Barents Sea are much larger than that that taken by the fishery, an impact of cod predation on shrimp abundance has not been demonstrated (Hvingel, 2006b). Consumption of shrimp by cod in the Barents Sea is shown in Figure 2.6.6.

Many abundant demersal fish species, including commercially important species such as haddock, feed on benthic worms, molluscs, crustaceans, and echinoderms during at least some periods of their life cycle. Haddock and the red king crab diet in the Barents Sea consist of echinoderms, mollusks and worms, which may indicate competition for food between these species. Haddock catches, mean individual length in catches, feeding intensity, frequency of occurrence of plankton, worms, mollusks and echinoderms were analyzed in a period with low (1971-1977) and in a period of increased (1995-2002) king crab abundance. The analysis did not reveal any trophic competition between the red king crab on the haddock feeding in the Russian part of the Barents Sea (Anisimova, et al. 2005). Bivalve molluscs, sea urchins, and small crabs are important prey of walrus, bearded seals and diving ducks (e.g. eiders) at depths under 50 m. Walruses may consume almost 60 kg of mollusks per animal per day and may have large local, at least transient, impacts on coastal benthic communities (Born et al., 2003).

Predators feeding on benthic prey are likely to be selective for size or individual taxa, but there is a lack in documentation to verify this. Similarly, quantitative assessments of direct impacts of fish, bird, and mammal foraging on benthic population and community structure have not been performed. In addition to direct removal of taxa during feeding foraging activities by walrus and bearded seals create considerable physical disturbance to the sea floor, which then significantly impacts the entire benthic community in areas around breeding colonies and favourite foraging grounds.

2.6.2.3 Zooplankton including jellyfish- competition, main prey and predators

The zooplankton community of the Barents Sea consists mainly of typical phytophages feeding on phytoplankton. However, there are also representatives of predatory plankton including *Chaetognatha*, most *Amphipoda* (*Hyperiidae*), *Pteropoda*, and also "jellyfish" – *Scyphozoa* (genus *Aurelia*, *Cyanea)* and *Ctenophora.* Large-scale predation of *Calanus* by ctenophores was observed in the Barents Sea in 1971 and 1983 (Fomin, 1985). *Chaetognatha* prefer rather large prey, such as small and large *Copepoda*, *Cirripedia* larvae, *Euphausiacea* and their larvae, also *Amphipoda*, fry of *Chaetognatha* and *Oikopleura*. The daily ratio in adult *Chaetognatha* of 10 %, equivalent to one meal in every 3-6 days, found in the North Sea, is probably representative for the situation in the Barents Sea also. Among two *Pteropoda* species, the smallest– *Limacina helicina* eats various planktonic organisms – *Crustacea* (*Copepoda*, nauplii), larvae of *Bivalvia*, *Tintinnidae*, *Dinoflagellata* and *Diatomea* (Foster 1987, Gilmer and Harbison, 1991). Migrating to the surface, *L. helicina* can form big concentrations attracting predators. These molluscs are food item for some fishes (capelin, herring), as well as seabirds and whales. *Hyperiidae* prey intensively on large and small *Copepoda*, *Chaetognatha*, *Euphausiacea* and even larvae of fish. The mentioned groups of predatory zooplankton are usually very abundant and can their abundance influence the structure of the plankton community in the Barents Sea.

Jellyfish feed on zooplankton but have few enemies, leading to "dead-end" pathways to higher trophic levels. The most striking example is the disastrous outburst of the ctenophore *Mnemiopsis leidyi* in the Black and Azov Seas, completely suppressing the development of fish biomass in these areas (Kidey, 1994). In the Barents Sea such dead-ends are unlikely to be important due to interspecies predation among jellyfish. The planktivorous ctenophore *Bolinopsis infundibulum* are rarely consumed by fish predators like cod and haddock, but it is consumed by the other ctenophore *Beroe cucumis*, which is also a year-round food item for lumpsucker *Cyclopterus lumpus* and a seasonal food item (in winter) for cod (Kamshilov et al.,1958; Kamshilov,1960; 1961). However, increasing of abundance of other jelly fish (*Scyphozoa*) might slow or even stop energy transfer from zooplankton to planctivors and predatory fishes.

Zooplankton is important food for several commercially important fish species in the Barents Sea. Important predators are immature herring, capelin, polar cod, as well as juveniles (especially 0-group) cod, haddock, saithe and redfish. In addition, other fish species have in recent years extended their distribution into the Barents Sea. For one of these species, blue whiting, the phenomenon appears to be transient as the species have now retracted from the area. The main pelagic fish stocks include a large proportion of zooplankton in their diet (Figure 2.6.2).

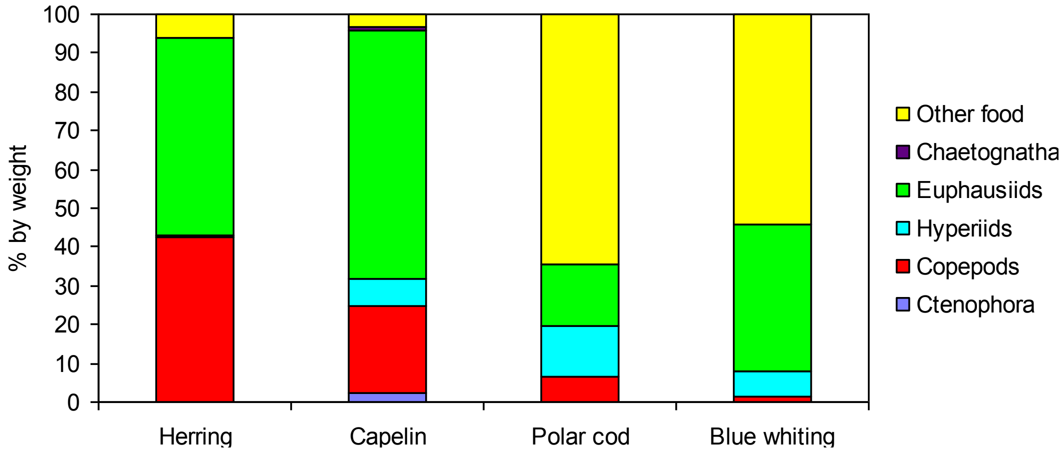

Figure 2.6.2. Averaged food composition of the most abundant planctivorous fish in the Barents Sea in 1984-2008, % by weight.

Zooplankton is also important for some adult demersal fishes in the Barents Sea, like cod, in years with low abundance of their preferred prey, and there is an inverse relationship between the amount of zooplankton in cod diet and the abundance of the preferred prey. Cod stomach content analyses showed that the 0 and 1 group cod fed mainly on crustaceans with krill and hyperiid amphipods comprising up to 70% of their diet. Krill (*Thysanoessa* spp. and *M. norvegica*) and hyperiid amphipods (Themisto spp.) were mainly found in cod stomachs sampled in the central and close to the Polar Front region in the Barents Sea where these prey organisms are reported to be abundant in summer. A shift in the main cod diet from zooplankton to fish is observed from age 1 to age 2.

A lot of the zooplankton production that is transferred to higher trophic levels in the Barents Sea ecosystem, is transferred through capelin. From the early 1980s till today the capelin stock has fluctuated significantly and the variations have profound impact on the zooplankton biomass and production. Even if many other factors influence the abundance and production of zooplankton, it seems to be close to an inverse relationship between capelin and zooplankton biomass (Figure 2.6.3).

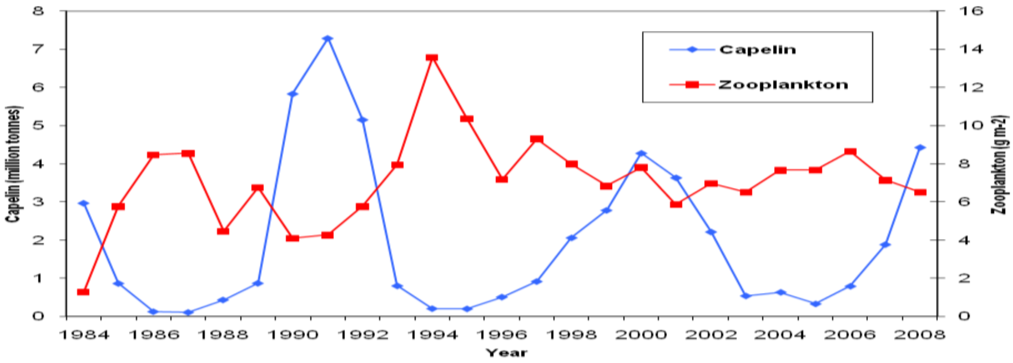

Figure 2.6.3. Annual fluctuations in zooplankton biomass and size of capelin stock in the Barents Sea

The effect of capelin on zooplankton abundance is also reflected in the spatial distribution of zooplankton. Figure 2.6.4 shows that the areas of high densities of capelin (high Sa values) and high TFI (total fullness index) reflected by low densities of zooplankton.

Zooplankton is also important prey for seals, baleen whales and some species of sea birds, such as little auk. Pelagic feeding marine mammals, including both seal and whale species, feed primarily on schooling prey including both fish and zooplankton (e.g *Themisto libellula*, *Gonatus fabricii*, *Thyssanoessa* spp. and *Meganyctephanes norvegica*). Interactions between pelagic marine mammals and their pelagic prey in the Barents Sea appear to be both strong and complex. Skern-Mauritzen and colleagues have done a detailed study from 2003-2007 of baleen whale distribution in years with low capelin abundance. Baleen whales in arctic waters were restricted to a narrow band along the northern and eastern rim of the pelagic fish distributions, suggesting that they target zooplankton rather than pelagic fish.

Little auk is the most specialized planktivorous sea birds, feeding exclusively planktonic crustacean, with calanoid copepods (*Calanus* species) accounting for 84-96% of the energetic content of chick meals across their range (e.g., Pedersen and Falk 2001). Northern fulmars also forage mostly zooplankton including jellyfishes, while for most fish-eating sea birds zooplankton become important alternative food in the cases of low fish availability.

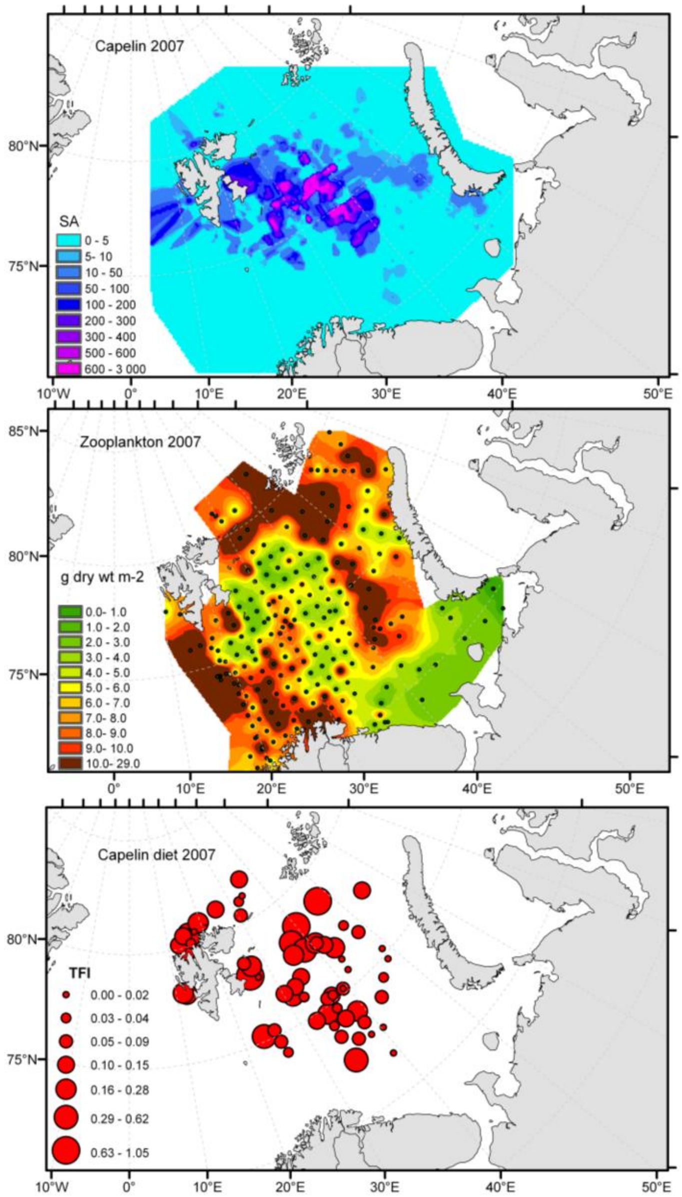

Figure 2.6.4. Distribution of capelin Sa values (Anon 2007), zooplankton biomass and capelin stomach content expressed as Total Fullness Index (TFI - dry weight).

2.6.2.4 Fish - competition and main predators

Fish in the Barents Sea can be classified into planktivorous, benthivorous and piscivorous, but many of them have a wide diet and a diet that changes with size. Fish species that feed on the same prey and that overlaps spatially are potential competitors. Capelin and polar cod overlap on the border of their feeding areas which is in the southeastern and central areas of the Barents Sea in cold years and in the northeastern areas in warm years. Capelin and polar cod have similar food ranges and rhythms of feeding, therefore, food competition may arise between them. For example, in the Admiralty Island area food competition was very pronounced in 2007 (Figure 2.6.5), resulting in different food used by the two species. However, north of the Novaya Zemlya shallows, food supply was high in this the same year. Here competition was probably low even though capelin and polar cod of all sizes fed on copepods (Figure 2.6.5) resulting in different food used by the two species.

Capelin is a key species in the Barents Sea ecosystem, and one of the main components in the transfer of trophic energy from lower to higher trophic levels. Capelin can have important impact on zooplankton abundance (above), and on the feeding behaviour and condition of their predators. Many predators in the Barents Sea, including cod, sea birds and marine mammals have capelin as their preferred prey. In years when capelin abundance is low, the predation on alternative prey is larger (Figure 2.6.4 and 2.6.6). Pelagic fish can be both competitors to, and prey for, marine mammals. This is also the case for cod. The strength and type (e.g., competition or predation) of interactions between pelagic fish, cod, sea birds and marine mammals seems to depend largely on the relative abundances of pelagic fish and zooplankton within the ecosystem at a given time (Haug et al., 2002; Sivertsen et al., 2006; Gjøsæter et al., 2009).

Capelin abundance fluctuate dramatically in the Barents Sea system, and have impacts on the distribution, and inter-annual diets of many marine mammal and sea birds species as well as piscivorous fish. Gjøsæter et al. (2009) studied the ecosystem effects of the three capelin stock collapses which have taken place since the mid-1980s. These stock collapses occurred in 1985-1989, 1993-1997, and 2003-2006. When capelin biomass was drastically reduced, its predators were affected in various ways. The cod experienced increased cannibalism, the growth was reduced and the maturation delayed. Sea birds experienced increased rates of mortality and total recruitment failures, and some breeding colonies were abandoned for several years. Harp seals experienced food shortage, increased mortality because they invaded the coastal areas and were caught in fishing gears, and recruitment failures. The three capelin collapses affected the predators differently. The effects were most serious during the 1985-1989 collapse and could hardly be traced during the last collapse. It was concluded that these differences likely result from increased availability of alternative food sources during the two last periods of collapse.

Cod is the most important predator on fish in the Barents Sea. Cod has a wide diet and feed both on pelagic and demersal fish, zooplankton and benthos, such as shrimp. The consumption by cod in the period 1984-2008, is presented in Figure 2.6.6. Overall, capelin is the most important prey of cod. In 2008 the proportion of capelin was 40%, followed by krill (13%), polar cod, haddock, shrimp, cod and hyperiid amphipods. Cannibalism might be important for cod recruitment and is now at an intermediate level, while the consumption of haddock by cod is at a record high level.

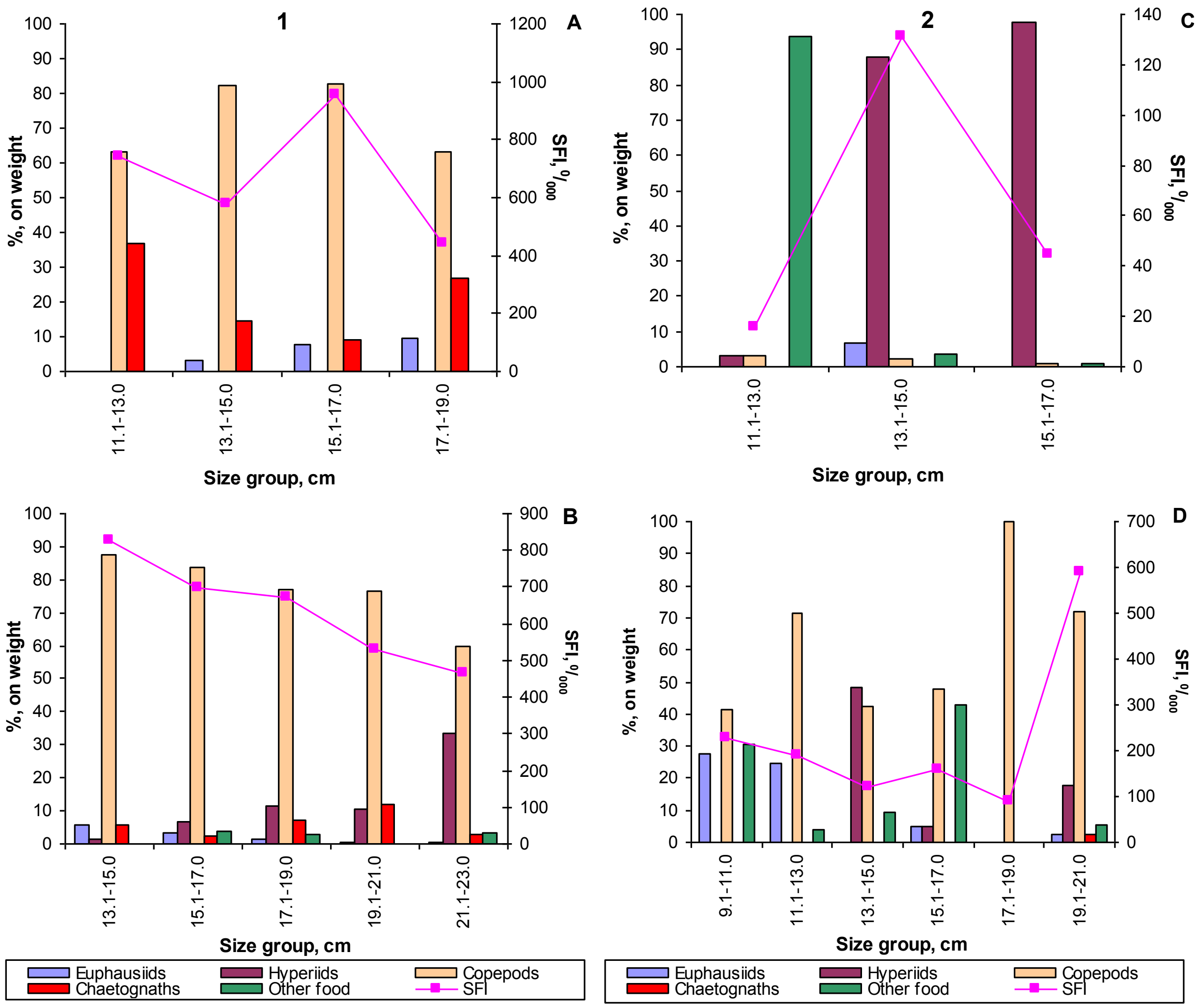

Figure 2.6.5. Food composition and consumption intensity by capelin (A, C) and by polar cod (B, D) from different size groups in the north of the Novaya Zemlya Shallows (1) and on the Admiralty Island area (2) in September 2007.

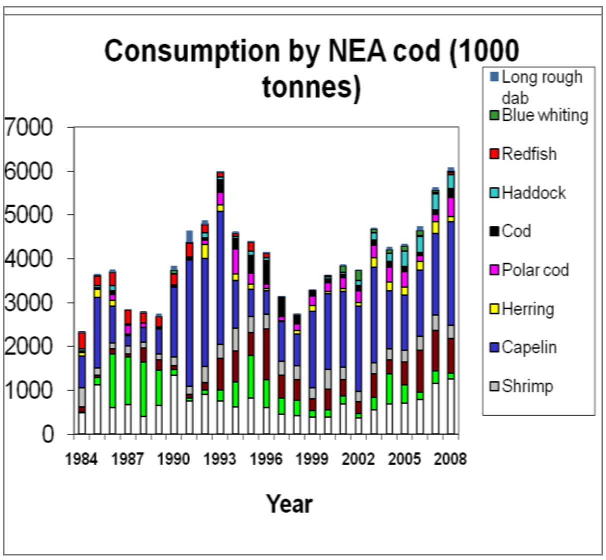

Figure 2.6.6. Consumption by Northeast Arctic cod in the period 1984-2008.

2.6.2.5 Predation by mammals

Minke whales and harp seals are the most important marine mammal predators with respect to fish consumption. Consumption estimates for minke whales (Folkow et al., 2000) and harp seals (Nilssen et al., 2000) are shown in Figure 2.6.7. These estimates are based on stock size estimates of 85 000 minke whales in the Barents Sea and Norwegian coastal waters (Schweder et al., 1997) and of 2 223 000 harp seals in the Barents Sea (ICES 1999/ACFM:7). Consumption by harp seal is calculated for situations with both a large and a small capelin stock, while consumption by minke whales is calculated for a situation with a large herring stock and a small capelin stock. Food consumption by harp seals and minke whales combined is at about the same level as prey consumption by cod (Figure 2.6.6). Thus, predation of fish by these two marine mammal species should be considered when calculating the mortality of capelin and young herring in the Barents Sea as their impacts are potentially significant.

The diet of marine mammals varies through the season, depending in part on where they are foraging. While most of the cetaceans leave the Barents Sea in autumn, harp seals can spend the entire year within the Barents Sea. The seals that breed and moult in the White Sea in spring perform extensive migrations covering large parts of the Barents Sea during summer, autumn and winter. They can also be joined by West Ice animals during the summer in the Northern Barents Sea, where the two stocks can overlap geographically for some months. In spring, when migrating through the southern Barents Sea, harp seals feed predominantly on fish, such as herring and small cod. Through the summer, they migrate northwards, and their diet switches to polar cod and krill, and in the autumn amphipods and capelin tend to dominate.

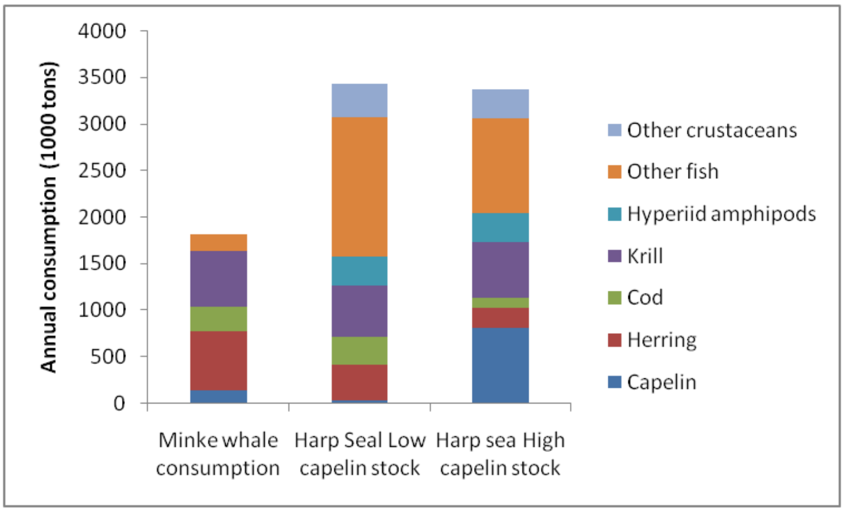

Figure 2.6.7. Annual consumption by minke whale and harp seal (thousand tonnes). The figures for minke whales are based on data from 1992-1995, while the figures for harp seals are based on data for 1990-1996.

Additionally, there is considerable interannual variation that is based on prey availability. For example, harp seal consumption estimates show very strong patterns that are affiliated with abundance of various fish stocks through time (Figure 2.6.8). Minke whales show similar levels of variation in the prey they target through time. In the period 1992-1999, the mean annual consumption of immature herring by minke whales in the southern Barents Sea varied considerably (640 t –118 000 t) (Lindstrøm et al., 2002). Most of the herring consumed belonged to the strong 1991 and 1992 year classes. But, there was a substantial reduction in the dietary importance of herring to whales after 1995, when a major part of both the 1991 and 1992 year classes migrated out of the Barents Sea and into the Norwegian Sea. This migration reduced the role of herring as a prey species for marine mammals in the Barents Sea, which was reflected by a more northern minke whale distribution in 1995 compared to earlier years (Eriksen, 2006). However, the importance of herring as prey increased in the Norwegian Sea in 1995, where minke whales seemed to track the migrating herring towards the Polar Front, thus reducing the role of shelf feeding observed in minke whales prior to 1995 (Eriksen, 2006). The dietary importance of herring to minke whales appeared to increase in a non-linear relation with herring abundance, indicating that minke whales switch to alternative prey species when herring abundance decreases below a certain level (Lindstrøm et al., 2002).

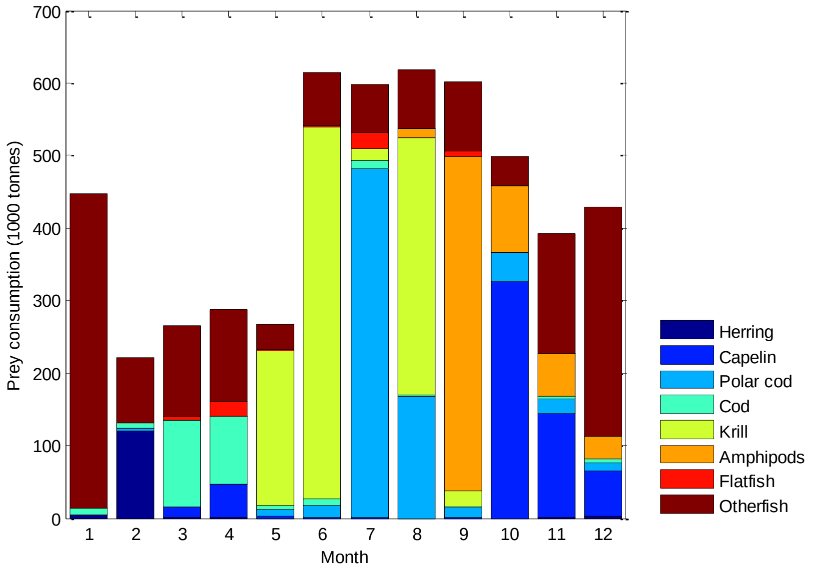

Figure 2.6.8. Monthly variation in harp seal consumption through the year.

Table 2.6.1. Annual consumption by minke whale and harp seal (thousand tonnes). The figures for minke whales are based on data from 1992-1995, while the figures for harp seals are based on data for 1990-1996.

Prey	Minke whale consumption	Harp seal consumption	
		Low capelin stock	High capelin stock
Capelin	142	23	812
Herring	633	394	213
Cod	256	298	101
Haddock	128	47	[1]
Krill	602	550	605
Hyperiid amphipods	0	304	313[2]
Shrimp	0	[1]	[1]
Polar cod	[1]	880	608
Other fish	55	622	406
Other crustaceans	0	356	312
Total	1817	3491	3371

[1] the prey species is included in the 'other fish' group for this predator
[2] only Themisto

During IMR ecosystem cruises in August-September 2003-2007 information on spatial distribution of marine mammals relative to prey distributions have been collected. During this time the Barents Sea system had low densities of capelin, a major forage fish for the pelagic marine mammals in the Barents Sea under normal circumstances. While the capelin was distributed in the central Barents Sea, abundant herring and blue whiting stocks were distributed in the southern Barents Sea and an abundant polar cod stock occurred in the northern Barents Sea (Figure 2.6.9). The main baleen whale species - minke, fin and humpback whales - were predominantly observed in Arctic Water masses north of the Polar Front. Only a small proportion of the minke and fin whales observed occurred in the southern Barents Sea (Figure 2.6.9). Furthermore, the baleen whales observed in the northern parts of the Barents Sea were typically aggregated at the rim of the capelin and polar cod distributions (Figure 2.6.9), in areas with elevated densities of larger zooplankton. This implies that the baleen whales, at least in years with low capelin densities, target other prey species such as the larger zooplankton. Furthermore, this aggregated distribution suggests that i) the baleen whales avoid areas with the highest pelagic fish densities, possibly due to prey depletion in these areas, and ii) that baleen whales and pelagic fish in arctic waters are competitors and that this competition structures the baleen whales' distributions. Being large-bodied, homoeothermic animals, the baleen whales require a high feeding rate, which may limit their distributions to areas which have forage fish stocks which have not been depleted by pelagic fish. In the southern Barents Sea, both fin and minke whales aggregated at high herring and blue whiting densities in recent years, indicating that target pelagic fish in this area. Nevertheless, the low density of baleen whales in southern BS suggests that the abundant southern pelagic fish stocks experience relatively low predation pressure from baleen whales, even when capelin abundance is low.

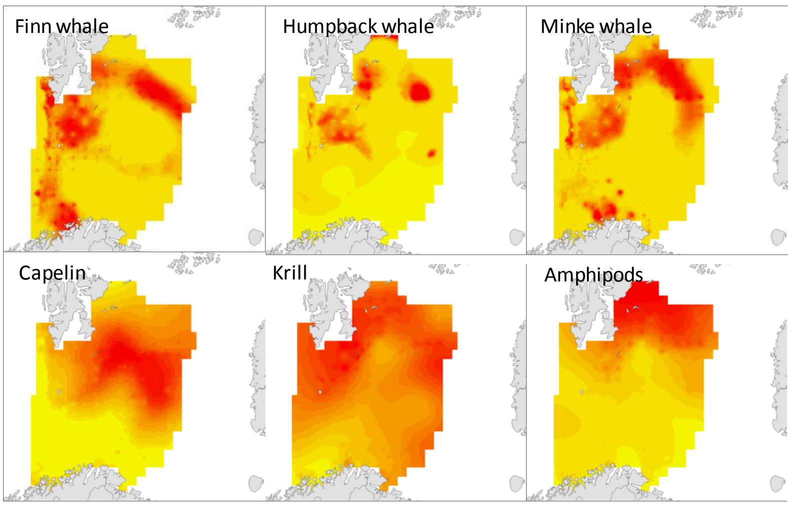

Figure 2.6.9. Modelled mean distribution of three baleen whale species (fin, humpback and minke whales) and relevant prey species (capelin, krill and amphipods) based on observations from ecosystem surveys August-September 2003-2007.

2.6.2.6 Seabirds – relation to prey populations

The preferred prey stocks of seabirds have undergone large variations the last decades, either because of overfishing or other variation in the ecosystem. The variation in capelin biomass is for example described above. These large fluctuations 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 (summarized in e.g. Krasnov and Barrett 1995, Barrett and Krasnov 1996, Barrett et al. 1997, Barrett 2007).

2.6.3 Human impact

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The Barents Sea is strongly influenced by human activities. Historically, this involves fishing and hunting of marine mammals. More recently, human activities also involve transportation of goods, oil and gas activities, tourism and aquaculture. This chapter focus mainly on impact from human activities that occur today in the Barents Sea. Past harvest of populations which have had a lasting impact on the ecosystem are also described. Impacts from expected long term changes due to global warming and ocean acidification are described in chapter 4.6.

Impact from different types of human activities are addressed in separate subchapters. The state of the environment in the Barents Sea is ultimately dependent on the overall pressure and impact of all the different activities that take place both within and outside the Barents Sea. To assess the combined impact of all drivers is a complicated task that lies beyond the scope of this report and a challenge that needs to be addressed further when developing ecosystem based management (see chapter 5.5). However, some steps of such analyses are done in chapter 4.5, where conclusions are drawn about overall impact of human activities on current status in the ecosystem.

2.6.3.1 Harvesting

Fisheries

For several centuries, fishing have played an important role in the function and dynamics of the Barents Sea ecosystem. In early periods fisheries were purely coastal and had limited effects on the ecosystem. With the development of offshore fisheries the impact on fish stocks and the ecosystem increased rapidly. At present, large-scale fisheries are one of the main factors determining the state and dynamics of the Barents Sea ecosystem.

The over-exploitation of demersal fish stocks, such as cod, haddock, redfish and Greenland halibut in the 1950s was the first large-scale disturbance in the Barents Sea ecosystem caused by fisheries. Technical management measures were introduced to limit the catches and to restore the depleted stocks. Despite positive effects of these measures, the redfish and Greenland halibut stocks did not fully recover. In 1970-1980, fisheries expanded from targeting demersal fish, which are top predators in the system, to target small pelagic fish and shrimps at intermediate trophic levels. As a response to this expansion, fishery management introduced a system which included both total allowable catch (TAC) and various technical means for protection of juveniles. During the last decades the exploitation of all main commercial species in the Barents Sea has generally corresponded to maximum allowable catches. As the overall impact by fisheries may influence the ecosystem stability (Filin et al., 2008), there is a need for including ecosystem components into fisheries management. The Barents Sea ecosystem seems to be particularly vulnerable when high fishing pressure coincides with adverse environmental conditions, such as in the middle of the 1980's when the capelin stock collapsed. It should be noted, however, that overfishing was not the main cause for the capelin collapse in the mid-1980s (see chapter 2.6.4).

Current fishing mortality contributes to keep stocks at a reduced abundance levels. However, stocks of cod, capelin, haddock and shrimp in the Barents Sea are currently managed sustainably, in the sense that fishing mortality is below the precautionary limits (F_{pa}) set by ICES, and stock sizes above the corresponding precautionary limit (B_{pa}). The stock sizes of Greenland halibut and the two redfish species (*Sebastes mentella* and *S. marinus*) are below B_{pa} partly due to overfishing. There are, however, signs of recovery in the S. mentella stock.

Fisheries in the Barents Sea do not only influence the targeted stocks. Due to strong species interactions fisheries removal of one stock may influence the abundance of other stocks. For example, herring collapses have positively influenced capelin abundance. Reduced stock sizes due to fisheries removal may also lead to changing migration patterns. Due to density dependent migrations, fish stocks cover greater areas and migrate longer distances when abundances are high compared to low. Fisheries also reduce the average fish size, age and age at maturity (further discussed in chapter 4.6.3). The reduced size and age of the cod stock may actually have altered the ecological role of cod as top predators in the Barents Sea.

Other indirect impact of fisheries include bycatch of non-targeted fish species, marine mammals and seabirds and gostfishing caused by lost fishing gear.

Fisheries' impact on seabirds and marine mammals

Fisheries have effects on seabirds and marine mammal populations in two different ways; through bycatch in fishing equipment as mentioned above and through removal of prey. Knowledge of the scale of seabird bycatch in the Barents Sea is fragmentary. Special incidents like the bycatch of large numbers of guillemots during spring cod fisheries in Norwegian areas have been documented (Strann et al., 1991). Gillnet fishing affects primarily coastal and pelagic diving seabirds, while the surface-feeding species will be most affected by long-line fishing (Furness, 2003). The population impact of bycatch will vary with the time of year, the status of the affected population, and the sex and age structure of the birds killed. Even a numerically low bycatch may be a threat to red-listed species such as Common guillemot, White-billed diver and Steller's eider. Also small marine mammals, e.g. seals and porpoises, are caught in fishing gears. The extent of this bycatch is not known, but bycatch is currently thought to be a threat to small coastal harbour porpoise populations living along the Finnmark coast.

The greatest impact of fisheries on seabirds and marine mammals may, however, be through the effect on their food base. Interactions between these top predators and fisheries are complex. In recent decades reduced prey availability has been a serious threat to many seabird populations, although the direct cause of these changes may be difficult to determine. Both fisheries and climatic variations are likely important. The capelin collapse in the 1980s also adversely affected both seabird and marine mammal populations (Vader et al., 1990, Nilssen et al., 1998).

Fisheries' impact on benthos

Fisheries affect benthic communities through bottom trawling and dredging. Particularly areas with biotic habitats generated by aggregations or colonial growth of single species are vulnerable. Such habitat-generating species are represented by a wide range of taxonomic groups, e.g. *Porifera*, *Polychaeta*, *Cnidaria*, *Mollusca* and *Bryozoa* (e.g., reviews in Jennings, 1998; Auster and Langton, 1999; Kaiser and de Groot, 2000; Moore and Jennings, 2000). These biotic habitats house a high diversity of associated species and are examples of whole communities that can be managed within restricted areas. Trawling and dredging also affect single species with a life span which does not favour reproduction between the trawling events.

By reducing abundances of larger long-living and deep burrowing seston-feeders, and increasing abundances of small detritophagous animals, fisheries change the structure of the sublittoral communities. The damage to coral reefs are well known (Fosså et al., 2002), but the effects on soft sediment communities have only recently been quantified. In already disturbed areas, where the fauna comprise opportunistic, short-lived (r-selected) organisms, the trawl damage is less than in more pristine areas (Olsgard et al., 2008). Furthermore, combined effects of climate variability, trawling and dredging are believed to be the main factors reducing the benthos biomass up to 70 % in some areas of the Barents Sea (Denisenko 2001; 2007). In general, the response of benthic organisms to disturbance differs with substrate, depth, gear, and type of organism (Collie et al.; 2000). Effects of trawling may therefore be hard to determine, and global indicator species may be hard to find. The challenge for management is to determine levels of fishing that are sustainable and not degradable for benthic habitats in the long run.

Whaling and hunting

The great abundance and diversity of marine mammals in the Barents Sea attracted the attention of the earliest European explorers to the region. Industrial whaling started in the Barents Sea in the early 17th century. This resulted in abrupt reductions in whale abundances, and was the first pronounced, large-scale human induced change in the Barents Sea ecosystem. As a result of unregulated hunting the stocks of right whales in the Northeast Atlantic were almost extirpated around 1800-1850, and the northern right whale stock in the Northeast Atlantic has subsequently gone extinct. The closely related bowhead whale has not gone extinct, but it is critically endangered and has not shown signs of recovery despite its protected status. The current population in the Barents Sea is estimated to number between 10 and 100 individuals. Walruses, seals and polar bears were initially taken largely as a by-catch of northern whaling, but these animals have also been the subjects of significant commercial harvests over time in the Barents Sea and adjacent areas. When protected on Svalbard in

1952, about 200 walruses remained at Svalbard. The population is still low and Red-Listed. Harbour seals and grey seals as well as harbour porpoise have been exploited throughout their range by coastal people from early human history in the region, and ringed seals, bearded seals, harp seals and white whales have also been harvested since the 1400s in coastal areas of the Barents Sea (Alekseeva, 2008).

Most marine mammal species in the Barents Sea are currently protected from exploitation. Only harp seals and minke whales are harvested commercially by Norway and this is done within sustainable limits. In Norwegian areas, sport hunting for ringed and bearded seals occur without any significant effects on the populations. However, there is a potential risk to small populations of coastal-living seals within Norwegian territories in the southern Barents Sea because of policies aimed to reduce the populations to avoid conflicts with inshore fisheries and aquaculture. Both grey and harbour seals have been hunted at levels that are almost certainly not sustainable in Troms and Finnmark counties in recent years (Nilssen and Haug, 2007; Frie and Kondakov, 2008; Nilssen et al., 2009). In the White Sea, ringed, bearded and harp seals and beluga whales are all hunted based on quota systems. Current quotas for White Sea harp seals are not sustainable (Chernook and Boltnev, 2008), but the actual harvest level during the past couple of decades has been well below the calculated sustainable limit (ICES, 2008). In 2009 there was no commercial harp seal hunt in this region. The small beluga harvest (100-150 individuals) is likely within sustainable limits. The other hunts are difficult to assess due to no recent available abundance data. West Ice harp and hooded seals have been the subject of centuries of commercial harvest; though due to precipitous declines in the latter species since WWII, hooded seals are now Red-Listed both in Norway and internationally and the West Ice quota (Norwegian and Russian hunting area) is set at zero (ICES, 2008; Salberg et al., 2008).

Despite what is, in hindsight, a repeated, tragic history of over-exploitation, the marine mammal community of the Barents Sea region is still rich in species, and some populations, particularly among the pinnipeds, are very abundant (Table 2.4.2, Figure 2.4.27). However, the large-scaled removal of top predators must have influenced the intermediate and upper trophic levels of the Barents Sea ecosystem. It is likely that predation pressure on krill and small pelagic fish species decreased, which may have benefited other top predators in the system such as gadoid fish. However, due to limited knowledge on the ecosystem prior to this removal, we do not know how the removal has changed the system.

Seabird harvest

Harvesting of seabirds has a long tradition in the Barents Sea region, and used to be widespread and important (Gavrilo 2008, Strøm et al., 2008). Today, the extent of harvesting is reduced and subject to strict regulations. Egging, down collection and harvesting of adult birds and chicks were important commercially and as a food supply in the past for the rural residents of coastal northern Norway (Wold, 1981; Bakken and Anker-Nilssen, 2001). In Svalbard, common eiders have been harvested since the 16th century, but reliable harvest data exist only from the middle of the 18th century onwards (Norderhaug, 1982). Large amounts of eggs and down were collected and the population declined greatly before it was protected in 1963. Hunters also visited seabird colonies where they collected eggs and adult birds. At Bear Island, 50,000-60,000 eggs were collected annually between 1952-1958, mainly from common and Brünnich's guillemots. This activity was stopped in 1971 (Rossnes, 1981). The most extensive harvest in the Russian seabird colonies occurred in Novaya Zemlya.

Commercial seabird harvest in Russia by Russians and foreigners (mostly Norwegians) started in the 19th century, and up to the start of the 2000 century, tens of thousands of birds and their eggs were collected annually (Sidorov, 1873; Ukhtomski, 1881). Seabird harvest peaked in 1920s – 1950s. At Bezymyannaya Bay (one of the largest seabird colonies on Novaya Zemlya) 342,500 Brunich's guillemot eggs were collected and more than 12,000 adult birds were killed in 1933 (Krasovski, 1937). During World War II, guillemots and their eggs were collected on Novaya Zemlya as a valuable food supply for the starving citizens of Archangelsk. In the late 1940s the harvest was restricted and protected areas were established. Nevertheless, dramatic decline in exploited colonies were observed. The commercial harvest was closed in 1954 after a nuclear testing ground had been established on the archipelago and the local population had been transferred to the mainland. No seabird colonies along the Murman coast have been harvested extensively.

2.6.3.2 Pollutio*n*

Despite that there are and have been few local source of contaminants, and the Barents Sea is one of the "cleanest" oceans in the world, animals on the top of marine food web such as polar bears and sea birds (e.g glaucous gulls) exhibit high concentration of some hazardous substances.

Contaminants that pose a risk to marine birds and mammals are especially POPs. The lipophilic (dissolves in fat storages in living organisms) nature and persistence of these compounds contribute to their bioaccumulation and biomagnification in marine food webs. These compounds are a particular problem in arctic animals because of their accumulation and subsequent seasonal cycling of lipid stores (which have accumulated high levels of toxins).

Legacy POPs are chemicals that have been banned or restricted (as a part of the Stockholm convention). Reduction in use, have resulted in declining levels that are transported in to the area, but due to their persistence, they remain in the environment. Examples are PCB, HBC and DDT. At high levels, these substances can inhibit immune-system function or cause developmental problems in fetuses or young animals (e.g AMAP, 2009; Gabrielsen, 2007).

A major challenge is to understand the impacts of POPs in the wildlife and to link effects seen in animals to a specific cause, such as load of chemicals. There are always a number of factors that simultaneously affect the health of an animal, like infections, predation, climate change and food scarcity. This makes it difficult to prove cause-effect relationships for one specific stressor. There are however strong indications that contaminants have affected the vitality of the polar bear populations around Svalbard and recent studies of biological effects of POPs have been able to confirm the casual link between POPs and observations of adverse effects in

Arctic top predators. These controlled experiments show effects on hormone, immune and reproductive systems. These effects are mainly due to breakdown products from the pollutants, indicating that these may be more important than the original POP compounds (AMAP, 2009).

Levels of contaminants presently found in Brünnich’s guillemots on Bear Island and Levels of contaminants presently found in Brünnich’s guillemots on Bear Island and Kongsfjorden are not considered to affect survival and reproduction of this species, but may have effects under nutritional stress (Gabrielsen, 2007). Studies of the glaucous gulls at Bear Island show correlations of e.g. adult survival, breeding success and high levels of PCB (Bustnes et al., 2006), and even lower levels of contaminants may affect the birds when food availability is low (Helberg et al., 2005; Bustnes et al., 2008). Levels of PCBs and DDEs determined recently in the ivory gull eggs from the northern Barents Sea appeared to be among the highest measured in seabird eggs in the Arctic (Miljeteig et al., 2009). Species at the top of the food chain are most vulnerable to the accumulation of environmental pollutants and many seabirds belong to this group (Gabrielsen, 2007; Letcher et al., 2009).

Other contaminants of concern are radioactive substances that may have harmful effects on population and the ecosystem. For details see pollution-related texts in chapters 2, 4 and 5.

2.6.3.3 Oil and gas activities

Major impacts on the ecosystem in the Barents Sea from oil and gas activities have so far not been documented by monitoring or by research. There are uncertainties associated with potential effects of seismic activities.

Seismic surveys

Seismic sound has both physiological and behavioural effects on marine life. The physiological effects are limited to areas very close to the sound source. Behavioural effects may one the other hand extend tens of kilometres from the seismic vessel. Considerable uncertainties are associated with understanding the impact from these behavioural effects.

Physiological effects on fish are limited to within 5 meters of the sound source. Within this range fish can be stunned or even killed. The younger life stages of fish, such as larvae and fry are more exposed to seismic lethal impacts due to lower abilities of escaping the seismic sources (Holliday et al., 1987; Booman et al., 1996). Simulation studies have shown no significant population level effects on fish from these very local effects on survival from seismic activities (Sætre and Ona, 1996) In marine mammals, hearing damage may occur, but only in individuals that are within 100 meters of the sound source. Because most marine mammals will leave areas where seismic surveys are performed, physiological damage to hearing is probably limited. The possibility for physiological damage beyond hearing damage is limited in mammals.

Fish behaviour may be significantly affected by seismic activity. Adult fish often leave areas with seismic surveys, and this scaring effect has been demonstrated as far as 33 km from the seismic vessel. Within influential areas, catches of cod and haddock have been reduced by 45-70 % depending on species and fishing gear (Løkkeborg and Soldal, 1993; Engås et al. 1996). In 2009 the Norwegian Ministry of Petroleum and Energy initiated a large scale research project in connection with seismic surveys in Lofoten/Vesterålen. The object of this research project is to study the behavioural effects of seismic sound on fish. The results of this project will be published in 2010.

As mentioned above, a behavioural effect on marine mammals is that they leave areas where seismic activities occur. In addition, sound from seismic air guns may disturb communication between mammals through masking of sounds. Seismic activities may also disturb foraging and other behaviours and reduce prey availability through the above mentioned scaring effects on fish (Gordon et al., 2003; Stone, 2003). Cetaceans have highly developed auditory organs, as they may use sound for both communication and localization of prey. Therefore cetaceans may be among the species most sensitive to seismic surveys. The frequency of airgun sounds overlaps more with the lower frequencies used by baleen whales than it does with the high frequencies used by toothed whales. Still, seismic surveys also emit high frequency sounds that the toothed whales respond to (Madsen et al.; 2006). While scaring effects of seismic surveys have repeatedly been documented for ranges up to about 20 km (Stone, 2001; Potter et al., 2007), studies of any long term effects of seismic activity on whale foraging or on whale populations are lacking.

Operational discharges

The two most important types of discharges from planned operations are discharges of drill cuttings containing drilling fluid which will settle on the sea bed, and the discharges of produced water which will be mixed with the sea water and stay in the water column. Environmental monitoring in Norway in the 1980s showed severe pollution effects on the sea bed and on pelagic fish from discharges of drill cuttings drilled with oil based drilling fluids. This resulted in a ban on discharges of oil based drilling fluids from 1991. Similar effects from discharges of cuttings drilled with water based drilling fluid have not been identified. The discharges of both kinds of cuttings led to smothering effects up to 100 meters from the point of discharge, with local physical effect on benthic fauna.

Also in the Barents Sea, the discharges of oil based drill cuttings are prohibited. In addition, Norwegian authorities will normally not accept discharges of water based drill fluids or cuttings drilled with water based drill fluids. Cuttings from the top part of the well may be discharged until suitable technology for collecting the cuttings is available.

Environmental monitoring in the water column has so far shown no effects following the discharges of produced water.

Accidental discharges

There has so far been no significant accidental discharge of oil or chemicals in the Barents Sea. However, the risk for accidents will increase with increased activity, unless considerable measures are put in place to mitigate this (discussed in chapter 4.4.2). The impacts of acute oil pollution from accidental discharges on the marine environment are varied, and can be summarised as follows:

- Drifting oil slicks may contaminate seabirds and marine mammals that are closely associated with the water surface when feeding, diving or resting.
- Oil that drifts ashore may contaminate seabirds, and other birds and coastal marine mammals, which use the littoral and supra-littoral zone when feeding or resting. Under particularly unfavourable conditions, oil may affect a considerable proportion of the populations of vulnerable species such as the common guillemot and the Atlantic puffin.
- Oil that drifts ashore may foul or smother and cause damage to plants and animals in the littoral and supra-littoral zone, and may also penetrate deep into the soil and sediments. It will then leach into the water, causing long-term exposure to oil and have toxic effects.
- Oil that dispersed or dissolved in the water masses may have toxic effects on fish (particularly eggs and larvae) and planktonic organisms. Under particularly unfavourable conditions (e.g. small populations congregating in small breeding areas to spawn) it may also affect a substantial proportion of a year class of fish.
- Oil drifting on the sea and/or that drifts ashore will reduce the recreational value of affected areas for varying lengths of time.
- Oil pollution may result in restricted access to certain areas and restrictions on sales of seafood for varying lengths of time, and this may have an impact on the fisheries and aquaculture industries.

While considering ecological effects of oil spills in the Barents Sea one must take into account some specific traits of Arctic ecosystems structure, especially the relatively high abundance of seabirds and marine mammals in comparison with other climatic zones. These groups of marine biota are known to be the most vulnerable to oil impacts. Patin (1999) has estimated that due to high local accumulation of seabirds in Arctic Seas there may be significant mortality from small oil spills (tens of litres). In the Norwegian as well as Russian parts of the Barents Sea there have been no significant discharges of oil or chemicals so far.

In order to assess the effects of petroleum exploration and production activities, statistical oil drift models are commonly used to simulate the drift of oil spills. These simulations are combined with modelled distributions of fish larvae or seabirds to assess impacts of accidental discharges on the populations. A small spill in areas with large congregations of fish, birds or mammals (for example during winter, breeding or feeding) could have greater impacts on populations than larger spills in areas where animals are dispersed.

Physical disturbance of the sea bed

Petroleum activities involve local disturbance of the sea-floor. The exploration drilling activities lead to physical disturbance through the anchoring of platforms, construction and lying of pipeline and the discharges of cuttings from the upper sections in the well. This disturbance might be detected by destructions of fragile habitats or by decrease/elimination of long-lived vulnerable animals for an unknown period.

To avoid damage to especially valuable and sensitive habitats like cold-water corals all proposed transects for pipelines, drill-sites, anchoring sites etc. have to be surveyed by video in order to place installations and pipelines in a way to avoid or mitigate damage. The probability of damaging habitats is further reduced/limited by the zero discharge target that restrict the discharges of drill cuttings and avoids contamination from produced water. However, discharges of drill cuttings from the top-hole section affect the habitat in a radius of 50-100m from the well hole by spreading fine sediments thereby smothering smaller filter-feeding organisms. Results from environmental monitoring indicate that this will not have any negative long-term effects.

Currently the Norwegian sector of the Barents Sea is little developed and the impact on the sea bed is therefore limited to the Snøhvit field and disturbance along the 160 km pipeline from Snøhvit to Hammerfest.

2.6.3.4 Shipping

Operational discharge

The day-to-day impacts of shipping on the environment are caused by ordinary operational discharges and of organotin compounds from anti-fouling systems. To protect ships against corrosion, zinc anodes are used in addition to special paint. If zinc anodes are used in ballast tanks, the 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, although no such impacts have been registered so far.

Emissions due to normal shipping operations are thought to have negligible or small effects on seabirds (Christensen-Dalsgaard et al., 2008). Individual birds may be affected by the small amounts of oil floating on the sea, but probably not to a degree noticeable at the population level. Chronic oil pollution must be considered as the most serious potential problem with regard to the possible consequences of ship traffic (without taking acute spillages into account). If large amounts of oil are released illegally, this may have serious consequences for seabirds. Chronic oil pollution along the Labrador and Newfoundland coast has annual impacts on seabird mortality at similar levels as the Exxon Valdez accident (Wiese et al., 2004).

Introduction of alien species

Today, the introduction of alien species through ballast water is considered to be one of the most serious threats to biodiversity in marine ecosystems. Thus, vessels from other parts of the world where the climate and ecological conditions are similar to those in the Barents Sea area may represent a great risk. However, we know very little about impacts of introduced species in ballast water in the Barents Sea. Alien species, particularly benthic species and species with a benthic stage in the life cycle, may also be introduced as fouling on ships' hulls.

Other impacts from ship transport
Ship transport poses risks to some marine mammals, particularly near the coast in the Barents Region. White Sea harp seals are currently experiencing considerable pup mortality due to shipping, when vessels break through the ice in whelping patches (Vorontsova et al., 2008). These sorts of issues are likely to represent increased risks to marine mammals in the Barents Region as retracting sea ice permits a longer shipping season, and increased potential for industrial activity.

2.6.3.5 Other activities

Tourism
The arctic environment is vulnerable and like many other human activities, tourism can have a wide range of impacts on the environment like pollution (oil, air, garbage, wastewater, ballast water), wildlife disturbance, and degradation of vegetation and historical and geological sites. Cruise-ship tourism is particularly intense in Svalbard, and to a lesser extent in Franz Josef Land in a Russian side but little is known regarding its consequences.

Aquaculture
Extensive sea farming is predominantly restricted to the Norwegian coast. Sea farming of salmon is the dominant activity, but farming of cod, halibut and blue mussels are growing. The major concerns regarding aquaculture are interactions between farmed species and wild populations of fish and shellfish when the farmed fish escape. Aquaculture can also lead to the introduction of exotic species (including disease and parasites) and increased abundance of pathogens. Nutrient enrichment from faeces, uneaten food and dissolved metabolites that end up in water and sediments can lead to local eutrofication problems in costal areas.

Chemical pollution from chemicals used to treat disease and parasitic infections will spread in the water and can be a local problem. Thus, aquaculture may result in loss of coastal habitats and creation of bottom dead-zones due to the build-up of organic matter. Aquaculture may also affect seabirds. Extensive development of mussel farming may interfere with sea duck feeding areas. Especially common eiders are attracted to mussel farms (Erikstad et al., 2006), where they may be disturbed or shot. Great cormorants *Phalacrocorax carbo* may feed on and damage salmon in the net cages, and may also be shot while interfering. However, traditional fish farming does not affect seabirds to any significant degree.

Wind power
Wind power plants will be an increasing factor in the coastal areas of the Barents Sea. One plant has been established in Finnmark, and several others are under planning. All planned parks are onshore, but in recent years, there has been an increasing focus on offshore wind turbine plants. Wind power stations can have various effects on seabirds: collisions increase mortality; loss and fragmentation of important habitat, reduced access to habitats due to barrier effects from avoidance of human structures, or decrease food availability due to human disturbance (Christensen et al., 2008).

2.6.4 Overall picture

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The purpose of this subchapter is to put together the pieces from the previous subchapter and discuss the overall dynamics of the ecosystem in the Barents Sea, including how it is affected by human activities and climate variability.

The dynamics of a large marine ecosystem must on the outset be considered to be complicated. One complicating aspect is that species are influenced not only by climate variability and human activities, but, as described in chapter 2.6.2, are also likely to influence the dynamics of each other to a large extent. A further complicating issue is that species may also affect each other indirectly. For example, if species A affects the dynamics of species B, and B in turn affects species C, A can affect C indirectly through the effect on B. Such indirect effects can significantly influence the overall dynamics of an ecosystem (Pimm, 1994; Yodzis, 2000; Bogstad et al., 1997), underlining the complexity of the overall dynamics.

For the Barents Sea, some key features of the dynamics of the ecosystem are nevertheless fairly well known. Here we will describe those aspects of the dynamics. We will also highlight aspects of the dynamics that are not well known by science, but that may potentially be important for the overall dynamics. The influence of climate variability and human activities will be considered throughout.

2.6.4.1 Key features of ecosystem dynamics

Atlantic and Arctic water masses are two major hydrographical domains in the Barents Sea, which determine the zoogeographical species composition in the ecosystem. The zoogeographical groups may be represented as “Mainly Arctic”, “boreal” or “Arctic-boreal”. Due to variability in distribution of Arctic and Atlantic waters in the Barents Sea alterations in distribution and relative abundance of arctic and boreal species are typical for the ecosystem.

Climate have an important effect on the amount of energy entering the system, both directly through affecting the production and indirectly through affecting the inflow to the Barents Sea. Climate variability also impacts fish stocks by altering recruitment, growth and migration patterns. The formation, melt and retreat of sea-ice in the Barents Sea provide physical conditions that influence the structure and function of pelagic and benthic communities.

Seasonal primary production is governed by nutrients and light, which again are modified by ice cover and vertical mixing of the water column. The Barents Sea is a high-latitude sea, characterized by increasing hours of daylight towards summer and decreasing hours of daylight towards winter. The length of daylight is also determined by latitude and hence modifies the length of the growing season of the primary production in the north-south axis.

An important part of any ecosystem is the pulse of primary productivity that comes into the ecosystem. In the Barents Sea this is mainly made up of phytoplankton and ice algae.

Phytoplankton is the most important component, but ice algae can be important in certain areas, in particular in the marginal ice zone. Energy also enters the Barents Sea ecosystem through zooplankton that drifts into the area from the Norwegian Sea.

Compared to other ecosystems the Barents Sea ecosystem is characterized by relatively short food chains. Zooplankton and benthos are the main groups feeding on phytoplankton and ice algae, and these groups thus channel the energy from the primary producers to the rest of the ecosystem. Important predators on zooplankton are capelin, herring , polar cod and some baleen whale species.

Pelagic fish species that feed on zooplankton form an intermediate trophic level. They are prey to larger fish, mammals and birds, which represent the top predators. It has been suggested that the trophic structure of the Barents Sea ecosystem is a “wasp-waist” system. In a “wasp-waist” system pelagic fish at the intermediate trophic level determine energy flux – from the lowest to the highest trophic levels – by regulating zooplankton through grazing they control the biomass available to top predators.

Capelin eats mainly krill and copepods, and the effect of capelin on zooplankton is so strong that a significant negative relationship can be seen between the amount of zooplankton in the Barents Sea and capelin abundance. Capelin also has profound effects on its predators (Gjøsæter et al., 2009). This has become evident during periods of collapse in the capelin stock. When the capelin stock collapsed in 1986, cod and several species of seabirds and marine mammals were negatively affected. For cod, individual growth and maturation slowed. The lack of food caused mass migrations of harp seal to the Norwegian coast, where many seals drowned in fishing nets. A large reduction in the abundance of some seabird species, especially common guillemot, was also observed. The two later capelin collapses in the mid-1990s and mid-2000s had less effect on the predators, probably because more alternative fish prey was available. Direct effects of fishing on capelin are not considered to be the prime cause of capelin collapses, although it should be noted that fishing made the first collapse more severe than it otherwise would have been.

Capelin often feeds in the northern and eastern parts of the Barents Sea, in the productive area near the marginal ice zone. Spawning takes part near the mainland shore in the southern part of the area. Capelin is therefore important for transporting energy from the marginal ice zone to the southern parts of the Barents Sea.

Herring, which only spend its first few years in the Barents Sea, is another important species for the overall dynamics in the ecosystem in the Barents Sea, mainly because young herring is an important predator on capelin larvae. There is at present no consensus among scientists about the causes of the observed capelin recruitment failures leading to capelin stock collapses. While no one holds the view that the causes are all known, some suggest that the collapses are mainly a consequence of predation on capelin larvae from increased amounts of juvenile herring, others suggest several factors as likely to cause capelin collapses, including climatic fluctuations, predation from fish and marine mammals, and fisheries. In years with high herring abundance in the Barents Sea, herring is are of course important in the food web as plankton feeders.

Cod is important for the dynamics in the ecosystem because it is the most abundant top predator in the ecosystem. In marine ecosystem with many similarities to the Barents Sea, large changes have occurred in the system after the collapse of cod stocks. The role of cod in different ecosystems is described by Link et al. (2009). The cod stock is smaller than it would have been without fishing. Large cod mainly prey on medium to large sized fish (e.g. young cod, haddock, flatfish). The predation pressure on the prey species should be less than without fishing on cod. It should also be noted that small cod as prey for larger cod (i.e. cannibalism) is one important factor in the cod stock dynamics, which may contribute to self-regulation of the stock.

The role of other abundant fish stocks such as haddock, redfish and Greenland halibut in the ecosystem should not be neglected. Haddock is an important predator on benthos, and we do not know whether haddock will be food-limited at the present record high levels. Redfish and Greenland halibut has both been depleted, and we do not know what effect this may have had on the ecosystem. In particular, the large amounts of young redfish, as seen in the Barents Sea until the 1980s but almost absent since, had clearly some impact on the ecosystem.

It is well established that populations of prey species can affect populations of seabirds and marine mammals (e.g. large effects of the collapse of capelin), but it is less well established that seabirds and marine mammals affect their prey populations. Given the slow rate of change in the populations of seabirds and marine mammals, the effects of these populations on their prey are probably slowly varying, except when the migration pattern changes, as was the case for harp seal in the late 1980s. It should be noted that a century or two ago, the population of several marine mammal species was probably much larger than at present, and this reduction in top predator abundance may have affected the ecosystem considerably (Nakken, 1998).

Long-range transboundary pollution is the main source to pollution in the Barents Sea. There are locally few sources to pollution. The only known impact on the ecosystem is effects on top predators (see chapter 2.6.2.3). Large-scale plans for oil and gas development as well as the transport of oil and other petroleum products are associated with a potential increased environmental risk to the Barents Sea ecosystem, unless counteracted by new technological development. The concentration of nuclear installations and location of radioactive waste storage facilities in Northwest Russia, as well as transport of radioactive waste and spent nuclear fuel to safer storage sites, represent a potential risk of radioactive contamination of the area, including the Barents Sea (see chapter 4.4.2 and 5.2).

For several centuries humans have conducted harvesting of fish and marine mammals in the Barents Sea. Consequences of this kind of human activities for the ecosystem are considered in detailed in chapter 2.6.3.2. Presently, the large-scale fisheries are one of the main factors determining the state and dynamics of the ecosystem in the Barents Sea. Fisheries do not only have direct effects on the target species, but also an indirect cascading effect that cascade through influence on predator and preys of the harvested species. Excessive catches of one species may lead to the collapse or population outbreaks of important predator or prey species and thereby cause changes in growth and survival patterns of other species in the food web. The impact of fishery on the harvested stocks may be especially large if this co-occurs with negative environmental impact. Important components of the overall ecological effect of fisheries also include habitant disturbances and by-catchers of seabirds and marine mammals.

Other groups which may be important, but for which we know less about function and dynamics:

- 0-group fish: In years with high recruitment, the biomass of 0-group fish in summer may be comparable to that of pelagic fishes, especially in the central areas of the Barents Sea (Dalpadado et al., 2009). Thus, 0-group fish can be important to the ecosystem both as predator and prey.
- Benthos: A large fraction of the primary productions goes through benthos. We know little about how benthos may affect other species. Climate and fisheries may affect benthos, and large variation has been seen.
- Jellyfish are an important predator on zooplankton, and possibly also on fish eggs and larvae, and little is known about their possible effect as competitor and predator.
- Wing snails are abundant, but very little known about their function in the ecosystem.

3 Monitoring of the ecosystem

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It should be recognised that many of the other authors of this report have contributed with background information and text to this chapter.

3.1 Introduction

To ensure the comparability of observation results 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 made at standard depths and on standard sections. At the beginning of the 20th century observations started on the Kola Section in the Barents Sea (Knipovich 1906), and by the 1930s, a network of such sections had been developed in the area (Figure 3.2.1).

In the last 50 years regular observations of ecosystem components in the Barents Sea have been conducted both at sections and by area covering surveys from ship and airplanes. In addition, there are conducted many long and short time special investigations, designed to study specific processes or knowledge gaps. Also, the quality of large hydrodynamical numeric models is now at a level where they are useful for filling observation gaps in time and space for some parameters. Satellite data and hindcast global reanalysed datasets are also useful information sources.

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

The observation system of the ecosystem and human activities in the Barents Sea are based on existing time-series of data collected by a number of Norwegian and Russian institutes. The contribution of different institutes to this monitoring is reflected in Tables 3.1.1-3.1.2.

Table 3.1.1. Contribution of different institutes to monitoring of the Barents Sea ecosystem.

Institute's abbreviation*	Ecosystem components						
	Climate	Phytoplankton	Zooplankton	Benthos	Fish and shellfish	Mammals	Sea birds
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). Utilisation of a measurement platform is essential for building up a broad knowledge of the ecosystem structure and variability, and therefore observations are conducted as broadly as possible. However, it is an impossible task to monitor all species in the ecosystem (e.g. ~3000 species of benthos, ~200 species of fish, ~25 species of marine mammals, etc). Therefore, historically, the main effort on biological monitoring is on the key species, but in the last years there have been more focus on species diversity and trophic interactions.

During a year an ecosystem component (e.g. zooplankton) is often monitored by multiple measuring platforms (e.g. sections, surveys, fixed stations, etc). Therefore this chapter is basically divided on two parts. The first part describes the monitoring "platforms", in a broad understanding of the word (chapter 3.2). The second part describes the monitoring from the ecosystem component perspective (chapter 3.3).

It should be emphasised, that even though the institutions participating in the preparation of this report are responsible for the vast majority of ecosystem monitoring in the Barents Sea, others are also conducting monitoring in this ocean. This report basically focuses on the monitoring conducted by the institutions that have contributed to the report.

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.

Institute's abbreviation*	Human activites and its impact						
	Fisheries	**Oil and gas**	**Pollution**	**Aquaculture**	**Shipping**	**Other activites**	**Threathened 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

Standard sections contain some of our longest marine time series, reaching back more than 100 years.

At the beginning of the 20-th century observations started on the Kola Section in the Barents Sea (Knipovich 1906), and by the 1930s, a network of such sections had been developed in the area (Figure 3.2.1). During the last decades, zooplankton has also been sampled at some of these sections. An overview of length, observation frequency and present measured variables for the standard sections in the Barents Sea is given in Table 3.2.1. Specific considerations for the most important sections are given in the following text.

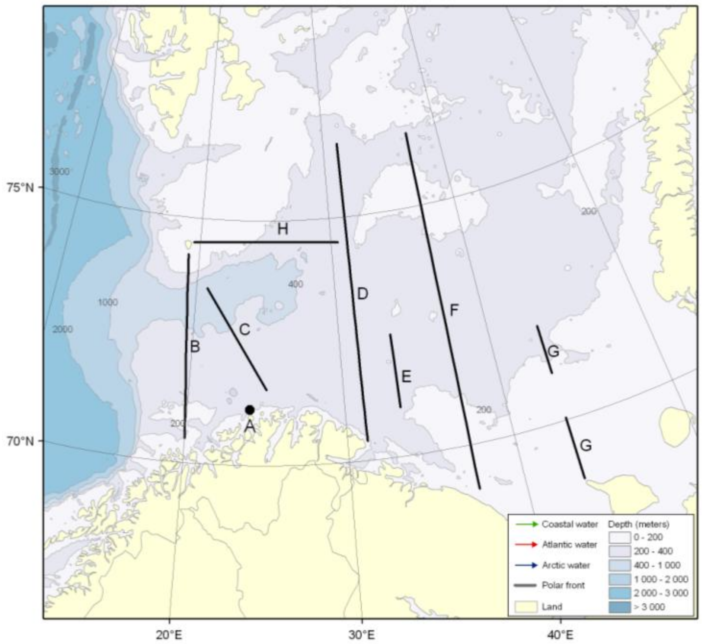

Figure 3.2.1. Positions of the standard sections monitored in the Barents Sea. A is fixed station Ingøy, B is Fugløya-BearIsland, C is North cape-Bear Island, D is Vardø-North, E is Kola, F is Sem Island-North G is Kanin section and H is Bear Island-East section.

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, zoo-zooplankton.

Section	Institution	Time period	Observation frequency	Parameters
Fugløya-Bear Island	IMR	1977 - present	6 times/year*	T, S, N, chla, zoo
North Cape-Bear Island	PINRO	1929 - present	1-26 times/year	T, S
Bear Island -East	PINRO	1936 - present	1-16 times/year	T, S
Vardø-North	IMR	1977 - present	4 times/year**	T, S, N,chla
Kola	PINRO	1900 - present	2-30 times/year	T, S, O, N, zoo
Kanin	PINRO	1936 - present	1-11 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. The section is therefore representative for the western part of the Barents Sea. It has been monitored regularly since August 1964, and the observation frequency increased to 6 times per year in 1977. Zooplankton monitoring began in 1987 and monitoring of phytoplankton algae from 2005.
Observations on the North Cape-Bear Island section have been conducted since 1929. It crosses the main branch of the North Cape Current. In the 1960s, the section was covered up to 26 times a year. In recent years it has been observed 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 the cold waters of the Bear Island Current. It is observed 1-2 times a year and shows the 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 the observation frequency increased to 4 times per year in 1977. Situated in the central Barents Sea it is the most representative section for the Atlantic branch going into the Hopen Trench, i.e. the central part of the Barents Sea. The northern part of the sections is usually in Arctic water masses. Zooplankton monitoring began in 1994 and monitoring of phytoplankton algae from 2005.

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

Observations on the Kanin section have been conducted since 1936. It crosses 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 observed 1-2 times a year.

Observations on the Sem Island section has been conducted intermittently since 1977. In the period 1977-1995 the section was observed regularly 2 times a year. Later it has been observed only a few times, with the latest observation in 2000.

IMR operates a series of fixed stations along the Norwegian coast. However, only one fixed station, Ingøy, is related to the Barents Sea. The Ingøy station is situated in the coastal current along the Norwegian coast. Temperature and salinity is monitored 1-4 times a month. The observations were obtained in two periods, 1936-1944 and 1968-present.

3.2.2 Surveys

Area-surveys are conducted throughout the year. The number of vessels in each survey differs, not only between surveys but may also change from year to year for the same survey. However, most surveys are conducted with only one vessel. It is not possible to measure all ecosystem components during each survey. Also, an investigation should not take too long time in order to give a synoptic picture of the conditions. Therefore the surveys must focus on a specific set of quantities/species. Other measured quantities may therefore not have optimal coverage. Thus considerable uncertainty may be associated with information on the latter, but the information may still be important. An overview of the measured quantities/species on each main survey is given in Table 3.2.2. Specific considerations for the most important surveys are given in the following text.

Table 3.2.2. Overview of conducted monitoring surveys by IMR and PINRO in the Barents Sea, with observed parameters and species. Species in bold are target species. For zooplankton, mammals and benthos abundance and distribution for many species are investigated. Therefore, in the table it is only indicated whether sampling is conducted or not. Parameters 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	-	-
Survey on estimation of abundance of young herring	PINRO	May	T, S	-	Yes	Pelagic species	Herring	-	-
Norwegian Greenland halibut survey	IMR	Aug	-	-	-	-	Greenland halibut, redfish	-	-

3.2.2.1 Norwegian/Russian winter survey

The survey is carried out during February-early March, and covers the main cod distribution area in the Barents Sea. The coverage is in some years limited by the ice distribution. Three vessels are normally applied, 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 targets for this survey. Swept area indices are calculated for cod, haddock, Greenland halibut, *S. marinus* and *S. mentella*. Acoustic observations are made for cod, haddock, capelin, redfish, polar cod and herring. The survey started in 1981.

3.2.2.2 Lofoten survey

The main spawning grounds of 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 current time series of survey data starts in 1985. Due to the change in echo sounder equipment in 1990, results obtained earlier 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 previous to 1990, the transects are not parallel, but more as parts of a zig-zag pattern across the spawning grounds aimed at mapping the distribution of cod. For practical reasons, trawl samples are not taken according to a proper trawl survey design. The spawning concentrations can be located with echosounder which effectively reduce the number of trawl stations needed. The ability to properly sample the composition of the stock (age, sex, maturity stage etc.) is limited by the amount of fixed gear (gillnets and longlines) in the different areas.

3.2.2.3 Norwegian coastal survey

In 1985-2002 a Norwegian acoustic survey specially designed for saithe was conducted annually in October-November (Nedreaas 1998). The survey covered the near coastal banks from the Varangerfjord close to the Russian border and southwards to 62° N. The whole area has been covered since 1992, and the major parts since 1988. The aim of conducting an acoustic survey targeting Northeast Arctic saithe was to support the stock assessment with fishery-independent data on the abundance of young saithe. The survey mainly covered the 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 more coastal areas, were also represented in the survey, although highly variable from year to year. In 1995-2002 a Norwegian acoustic survey mainly for coastal cod was conducted along the coast and in the fjords from Varanger to Stad in September, just prior to the saithe survey described above. This survey covered coastal areas not included in the regular saithe survey. Autumn 2003 the saithe- and coastal cod surveys were combined and the survey design was improved. The survey now also covers 0-group herring in fjords north of Lofoten.

3.2.2.4 Joint ecosystem autumn survey

The survey is carried out from early August to early October, and covers the whole Barents Sea. This survey encompasses various surveys that previously have been carried out jointly or at national basis. Joint investigations include the 0-group survey, the acoustic survey for pelagic fish (previously known as the capelin survey), and the investigations on young Greenland Halibut north and east of Svalbard. The predecessor of the survey dates back to 1972 and has been carried out every fall since. From 2003 these surveys were called "ecosystem surveys".

Normally five vessels are applied, three Norwegian and two Russian. Most aspects of the ecosystem are covered, from physical and chemical oceanography, primary and secondary production, fish (both young and adult stages), sea mammals, benthos and birds. Methodology for each of these groups is described in more detail in chapter 3.3. Many kinds of methods and gears are used, from water sampling, plankton nets, pelagic and demersal trawls, grabs and sledges, acoustics, visual observations (birds and sea mammals).

3.2.2.5 Russian autumn-winter trawl-acoustic survey

The survey is carried out in October-December, and covers most of the Barents Sea. Two Russian vessels are usually used. The survey has developed from a young cod and haddock trawl survey, started in 1946. The current trawl-acoustic time series of survey data starts in 1982, targeting both young and adult stages of bottom fish. The survey includes observations of physical oceanography and meso- and macro-zooplankton.

3.2.2.6 Survey on estimation of abundance of young herring in the Barents Sea

This survey is conducted in May and takes 2-3 weeks. It also includes observations of physical oceanography and plankton. In 1991-1995 it was a joint survey, since 1996 the survey ha been carried out by PINRO.

3.2.2.7 Norwegian Greenland halibut survey

The survey is carried out in August, and cover the continental slope from 68 to 80ºN, in depths of 400–1500 m north of 70º30'N, and 400–1000 m south of this latitude. This survey was run the first time in 1994, and is now part of the Norwegian Combined survey index for Greenland halibut.

3.2.3 Hydrodynamical numerical models

Large 3D hydrodynamical numeric models for the Barents Sea have, through validation with observations, proved to be a useful tool for filling observation gaps in time and space. The hydrodynamical models have also proved useful for scenario testing, and for study of drift patterns of various planktonic organisms. These models are developed and runned at several Norwegian and Russian institutions, at different scales and resolutions.

Sub-models for phytoplankton, zooplankton, fish larvae and even fish are now implemented in some of the hydrodynamical models. However, due to the present assumptions in these sub-models care must be taken in the interpretation of the model results.

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 in the skin (~1 m) layer. Several climate variables can 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 for monitoring several physical parameters associated with the sea surface as well as observations of mammals at the surface.
Along the Norwegian coast, ship-of-opportunity supply weekly the surface temperature along their path.

Tagging of fish and marine mammals has been used for many years to track the horizontal migration and vertical movement. The tags have historically been markers that only can give information about starting location and recapture location, but now electronic markers can monitor several parameters, such as position (through satellite signals when at surface), in situ temperature and salinity.

3.2.5 Databases

Databases are “platforms” of high use and importance in the further work and analyses of the data. Many databases exist, but few are linked. Most databases are often hard to access without a high level of expertise. However, work is ongoing in this field, both toward higher accessibility and to better linkage among the databases.

Of special interest can be mentioned the newly developed hydrographic Atlas for the Barents Sea (quarterly values), and the fish stomach databases at IMR and PINRO (contained approximately 380 thousand stomachs by the end of 2006, Dolgov et al., 2007).

Several international hindcast databases (e.g.. NCEP, ERA40) are available. They use a combination of numerical models and available observations to estimate several climate variables, covering the whole world.

3.3 Monitoring divided by ecosystem components

3.3.1 Climate monitoring

In order 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 at the joint winter survey and in August-October at the joint ecosystem survey. The standard sections also form an important base for the evaluation of temperature and salinity. Especially the seasonal development is monitored at the Kola and Fugløya-Bear Island section, and at the fixed station Ingøy. In the Fugløya-Bear Island section a series of current meters monitors give a high resolution of the flow through the western entrance of the Barents Sea. In addition hydrodynamical numeric models give insight into horizontal and vertical variation of temperature, water masses distribution and transports.

3.3.2 Phytoplankton monitoring

The bloom situation in the Barents Sea is covered on a regular basis both during the survey coverage in August-October and on the standard sections Fugløya-Bear Island and Vardø-Nord. From these surveys the chlorophyll concentration is measured in water samples taken from standard depths down to 100 m depth. This gives an indication on the primary production in the area. In addition to the chlorophyll concentration, part of the region is covered using a fluorometer on the CTD making continuous profiles of fluorescence at station from surface to bottom depth. From 2005 data on species composition and abundance have been retrieved from water samples, both during the Ecosystem survey and on the standard sections, covering approximately the same area as for zooplankton. In addition to observations, the primary production is simulated using numerical models.

3.3.3. Zooplankton monitoring

Zooplankton biomass and species distribution is monitored during the joint autumn ecosystem survey. Joint Russian and Norwegian zooplankton investigations have taken place since 2002. Regular sampling by IMR began in 1979 while PINRO has conducted these surveys since in 1982-1993. A Juday net (37 cm in diameter, 180μm) is used to obtain zooplankton samples by PINRO. IMR uses a WP2 net (56 cm in diameter, 180μm) and a $1m^2$ MOCNESS multiple plankton trawl with 9 nets all having a mesh size 180 μm, as standard zooplankton gears. The MOCNESS is mainly used for obtain better data on the vertical distribution of mesozooplankton and the gear is also somewhat more efficient with regard to the larger zooplankton components like arrow worms, krill and amphipods.

In 2005 comparisons were made between the Juday and WP2 net catches from the joint autumn cruises both with regard to biomass and species composition. The biomasses obtained by the two gears are quite similar. A report on the comparisons of the two gears was prepared at a joint meeting held at IMR in May 2006 and the EcoNorth symposium in Tromsø in March 2007. During the Ecosystem survey in August-September 2007 a specially designed double-net system, holding side by-side one Norwegian WP2 net and one Russian Juday net, was used to sample the water column at selected stations in order to compare the sampling efficiency of the two nets for various mesozooplankton components. A total of 19 hauls were conducted with the double-net system. Samples have been worked up for biomass comparisons, and a special workshop was arranged in Bergen 22-26 October 2007 where most of the samples were analyzed for species composition and abundance by Russian and Norwegian specialists. All double-net hauls were operated with a vertical speed of 0.5 m s^{-1}

from RV G.O. Sars. The analyses from this work are in due progress and will be reported at a later stage.

Monitoring of zooplankton along the Fugløya-Bear Island section by IMR started in 1987 and are 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 is sampled ~4 times a year. However, data prior to 1994 are scarce and does not give a full seasonal coverage. The WP2 plankton net has been used regularly during this monitoring since 1987. In addition vertically stratified MOCNESS tows are taken during the two-month Ecosystem survey in August-September each year, approximately one haul pr. day.

Regular macroplankton surveys have been conducted by PINRO in the Barents Sea since 1952. Surveys involve annual monitoring of the total abundance and distribution of euphausiids (krill) in autumn-winter trawl-acoustic survey. To collect macroplankton a net attached to trawl (trawl net) (0.2 m^2 opening area, 564-mm mesh size) was used. This net is a modification of egg net IKS-80 and it is attached to the headline of a bottom trawl and catch plankton near the bottom. During winter, crustaceans are concentrated in the near-bottom layer and have no pronounced daily migrations, and the consumption by fish is minimal. Therefore sampling of euphausiids during autumn-winter survey is used to estimate year-to-year dynamics of their abundance in the Barents Sea. Annually 200-300 samples of macroplankton are collected during this survey, and both species and size composition of euphausiids are determined. It is necessary to note that in spite of quite a large mesh size, the net can catch both small and large animals (Orlova et al., 2004a,b). In August-September in the north-eastern areas in the bottom layer (6-10 m above the bottom) are observed of young *Th. abyssorum* in length from 0.5 mm up to 4-6 mm, and *Th. libellula* (length 3.5-12 mm), as well as unidentified young hyperiids 1-6 mm in length (60-150 and 320 ind./1000 m^3).

Gelatinous zooplankton (ctenophores and cnidarians) are caught in both the WP2 net and the MOCNESS plankton trawl. However, it is questionable to which degree catches can be considered truly quantitative especially for the larger ctenophores and scyphozoans. In addition many species are damaged in nets. Thus their actual 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 we have chosen in this report to present catches from this trawl, normalized to $kg \cdot trawldistance^{-1}$, although caution should be exercised in their quantitative interpretation.

3.3.4 Benthos monitoring

Yearly monitoring of the shrimps and the benthos community are done in the joint autumn ecosystem survey. The joint autumn ecosystem survey will also supply a historical benthic mapping started by PINRO in the early 1930's, continued in the 1960's and followed up from year 2000. In addition, basic mapping of the bottom animals in the Barents Sea is done in the MAREANO project, which started its activity in summer 2006. Within the next few years the southern ice-free areas of the Barents Sea will be mapped in this project.

In addition to data on king crabs from the ecosystem survey, joint red king crab monitoring surveys has been maintained in the southern coastal Barents Sea every year. The king crab stocks and life stages are targeted at these surveys. In addition to catch data the surveys are the main data source for the assessment of the stocks.

Since 1982 annual trawl surveys were conducted to gather information on shrimp stock biomass and demographic composition for use in the assessment. From 2004 onward, the survey has been a joint Russian-Norwegian operation: “The Russian-Norwegian ecosystem survey of the Barents Sea”.

Analysing the Campelen trawl invertebrate by-catch is a time and cost effective method, which are easily implemented in the annual Russian and Norwegian Ecosystem scientific cruise. Since 2005 Russian and Norwegian benthic scientists has developed the method in order to secure standardized methods on both Russian and Norwegian ships (chap 4.3.3). The method still needs further development and needs to be verified with more quantitative tools for benthic sampling in order to investigate the validity of the Campelentrawl as a benthic sampler.

In order to make a method capable to follow biomass fluctuations in the Barents Sea, long term monitoring areas was established. The areas were selected from criteria’s such as time and cost realisms, human impacts and natural variation and geographical variation. The six areas have been discussed and represent following background (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	+	+		

Monitoring of benthos on the Shtokman field and in the Kola section has been done by MMBI. For the Kola section, the data stems back to 1930s. On the Shtokman field, monitoring has been done since 2002.

3.3.5 Fish monitoring

Most of the area surveys mentioned above have monitoring of commercial fish species as their main objective. The different fish stocks and life stages are targeted at these surveys. In addition to catch data, the surveys are the main data source for the assessment of the stocks.

Data on non-target fish species (abundance, weight, length distribution etc.) have also been collected on these surveys during the last ten years.

Among additional sources of information are biological data collected by Russian observers onboard commercial fishing vessels, and some regular fishing vessels with special reporting demands acting as reference vessels.

3.3.6 Mammal monitoring

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

Different methods are used for abundance estimation of the commercially important marine mammal species in the Barents Sea. Mark-recapture experiments have been conducted for determining the abundance of harp seals since the mid 1980s (e.g. Øien and Øritsland, 1995). More recently, the preferred method for estimating abundance of ice-breeding seals and pelagic cetaceans has become strip transect-surveys flown from aircraft for seals and done using ships for whales. Øritsland and Øien (1995) attempted the first survey of the West Ice in 1990/1991, but weather and ice conditions prevented calculation of a complete estimate. Since that time, aerial surveys have become more routinely conducted in the West Ice (Haug *et al.*, 2006; ICES 2008), as the International Convention for Exploration of the Seas (ICES) now require that quotas for harvesting marine mammal species commercially be based on estimates which are less than 5-years old.

The first aerial surveys of harp seals in the White Sea were conducted in 1927-28 at the time of moulting (Shafikov, 2008). Breeding surveys to estimate pup production in the White Sea have been conducted in 1998, 2000, 2002, 2003, 2004, 2005, 2008 and 2009 (Potelov et al. 2003; ICES 2008), and moulting surveys of harp seals have been flown 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 following the Second World War. The first successful aerial survey for hooded seals took place in 1997. New surveys were conducted in 2005 and 2007 (Salberg et al. 2008, ICES 2008). Regular monitoring of some marine mammals in the Barents Sea is carried out by sighting vessel surveys of cetaceans provide abundance estimates every 6 years. Regular monitoring sighting vessel surveys conducted by the Institute of Marine Research target minke whales and other large baleen whales. These vessel cruises are conducted annually, such that abundance estimates can be calculated for the overall region approximately every 6 years (Skaug et al. 2004).

Since 2002 the distribution patterns of marine mammals in the Barents Sea have been observed from research vessels during the ecosystem survey (see description of this survey above). In addition aircraft observations and observations from fishing and coastguard vessels with observers are used to explore the temporal and geographic distribution of some marine mammal species. Starting in 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 bowheads. Additionally, aerial surveys are conducted within MOSJ to determine the abundance of polar bears, ringed seals and harbour seals every 5 years and walruses once per decade. On the coast of mainland Norway, harbour and grey seals are monitored every 5 years (Nilssen and Haug 2007; Nilssen et al. 2009).

3.3.7 Seabird monitoring

The 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.).

3.3.7.1 Norwegian zone

The seabird monitoring programme for Svalbard was initiated in 1988 (Mehlum & Bakken 1994) and seven species are now (2009) included in the programme: northern fulmar, common eider, great skua *Catharacta skua*, glaucous gull *Larus glaucous*, black-legged kittiwake, common guillemot, Brünnich’s guillemot and little auk (Strøm 2006). Monitoring of population development is carried out annually for all seven species except little auk. Data on survival, breeding success and chick diet are monitored on Bear Island (Bear Island) for all species except northern fulmar; on Spitsbergen for black-legged kittiwake, Brünnich’s guillemot and little auk (Strøm 2006). The seabird monitoring programme in Svalbard is organized by the Norwegian Polar Institute, and data stored in the institutes Seabird Colony Database – COLONY (Bakken 2000).

The national monitoring programme for seabirds, established in 1988 and revised in 1996, addresses population changes 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 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, Svalbard and adjacent sea areas (Anker-Nilssen et al. 2005).

The formerly established monitoring activities, which include the national programmes on the mainland and Svalbard and long-term studies of seabird ecology on Røst, Hornøya and Bear Island are integrated parts of the SEAPOP programme. SEAPOP thus integrates all previous seabird monitoring activity into one programme (Anker-Nilssen et al. 2005a).

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	Litle 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	•		•	•		•		•	•	•		•	•	

The activities in 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 for monitoring of seabirds in Russia. Extensive seabird studies were initiated in the Russian part of the Barents Sea in the 1920-1930s and systematic studies on seabirds were started in 1938 in the Seven Islands archipelago (eastern Murman coast) at the same time as the archipelago was protected as a strict nature reserve. It also included two of the largest seabird colonies on Novaya Zemlya; Gribovaya and Bezymyannya Bays on the Southern Island, Novaya Zemlya, in 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 are within the territory of Kandalaksha State Nature Reserve (KSNR; including former Seven Island reserve). Monitoring in this reserve is concentrated in three areas including Kandalaksha Bay (White Sea) and West and

East Murman areas (south Barents Sea coast). For some 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 *Uria aalge* and Brunnich's guillemots *U. lomvia*, black guillemot *Cepphus grylle*, Atlantic puffin *Fratercula arctica*, black-legged kittiwake *Rissa tridactyla*, herring *Larus argentatus*, great black-backed *Larus marinus* and mew *Larus canus* gulls, arctic skua *Stercorarius parasiticus*, arctic tern *Sterna paradisea* 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 the remote areas on the Barents Sea coast was recently broken due to staff shortage and logistic problems in the KSNR. Monitoring has continued in the Kandalaksha Bay (total counts since 1970s) but now with reduced coverage. In addition to population numbers, monitoring parameters include productivity, diet and phenology.

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

3.3.8 Pollution monitoring

Today the monitoring in the Norwegian part of the Barents Sea is divided into two main groups: Monitoring on national level (financed by different ministries) and monitoring done on commission by the industry. A number of institutions take part in the regular national monitoring. A map showing location of the monitoring sites can be seen on the Russian-Norwegian environmental web portal (http://barentsportal.com.).

In addition to regular monitoring, the national program of geochemical, geological and biological mapping of the seabed of the Barents Sea, MAREANO, which started in 2006, will provide the most detailed knowledge on the levels of certain organic and inorganic pollutants that exists to date.

In Norway, the Norwegian Radiation Protection Authority coordinates the monitoring of the marine environment under the radioactivity in the marine environment (RAME) programme (funded by the Ministry of the Environment) and the monitoring of radioactivity in commercially important fish species (funded by the Ministry of Fisheries). This work is carried out in conjunction with the Institute for Marine Research and the Institute for Energy Technology.

Norwegian regulations and permits issued by The Norwegian Pollution Control Authority (SFT) require that oil companies carrying out drilling or production in Norwegian waters arrange for environmental monitoring to being carried out on a regular basis. Special baseline surveys must be carried out before any drilling is carried out. During production drilling and production of oil and gas, sediment, sea bed and water column monitoring must be carried out every 3 years. The detailed requirements may be found in the Activity Regulation, §§ 49-53.

In Russia, monitoring of chemical contamination in the environment and in marine resources in the Barents Sea was begun by PINRO in 1986.

Monitoring activity on exploration and production of hydrocarbons in the Barents Sea and other seas is conducted by the following divisions under guidance of the RF Ministry of Natural Resources: The Federal Subsoil Resources Management Agency (Rosnedra), the Federal Supervisory Natural Resources Management Service (Rosprirodnadzor) and the Federal Service for Ecological, Technological and Atomic Supervision (Rostehnadzor).

The governmental monitoring of the geological environment under the contract with Rosnedra has since 2001 been performed by Sevmorgeo.

Data about cruises of Federal monitoring are presented in annual bulletins about status environment of north-west seas and presented on the web site of Sevmorgeo: www.sevmorgeo.com.

Databases are as at executors of works and (data of federal monitoring) in the State fund of storage of the ecological information of Russia. They can be presented by special inquiry.
The types of pollutants, periodicity and the institute performing the monitoring is summarised in Table 3.3.3.

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 annual 1988- SFT/NIVA every 10-12 yers 1994- NGU, annual 2003- Sevmorgeo, annual 2005-	PINRO, annual 1986- Sevmorgeo, annual 2005-	PINRO, rarely 1986- SFT/NIVA annual 1994-	PINRO, annual 1986- SFT/NIVA annual 1994- NIFES, annual		NPI	SFT/NILU annual
PAH	IMR, annual 2003- PINRO, annual 1990- SFT/NIVA every 10-12 yers 1994-	IMR, irregular PINRO, annual 1987-	PINRO, rarely 1987- SFT/NIVA annual 1994-	IMR, every 3rd year 2002- PINRO, annual 1987- SFT/NIVA annual 1994-	-	NPI	SFT/NILU annual
THC	IMR, annual 2003- Sevmorgeo, annual 2005-	IMR, irregular Sevmorgeo, annual 2005-		IMR, irregular	-	NPI	
Alkanes	PINRO annual 1990-	PINRO annual 1986-	PINRO, rarely 1986-	PINRO annual 1986-			
DDT	IMR, irregular; SFT/NIVA, every 10-12 yers 1994- PINRO annual 1994-	PINRO annual 1994-	NIFES, annual; SFT/NIVA, annual 1994- PINRO, rarely 1994-	IMR, every 3rd year 2003- , NIFES, annual 2007-; SFT/NIVA, annual 1994- PINRO annual 1994-	-	NPI	SFT/NILU annual
DDT	IMR, irregular; SFT/NIVA, every 10-12 yers 1994- PINRO annual 1994-	PINRO annual 1994--	NIFES, annual; SFT/NIVA, annual 1994- PINRO, rarely 1994-	IMR, every 3rd year 2003- , NIFES, annual 2007-; SFT/NIVA, annual 1994- PINRO annual 1994-	-	NPI	SFT/NILU annual
Toxaphene	IMR, irregular	-	NIFES, annual	IMR, every 3rd year 2003- , NIFES, annual 2007-	-	NPI	
HCH	IMR, irregular PINRO annual 1994-	PINRO annual 1994-	NIFES, annual PINRO, rarely 1994- SFT/NIVA, annual 1994-	IMR, every 3rd year 2003- , NIFES, annual 2007- PINRO annual 1994- SFT/NIVA, annual 1994-	-	NPI	SFT/NILU annual

Table 3.3.3 Cont.

Pollutant type	Sediment	Water	Shellfish	Fish (muscle and/or liver)	Seaweed	Mammals and birds	Atmospheric pollution
HCB	IMR, irregular; SFT/NIVA, every 10-12 yers 1994- PINRO annual 1994-	PINRO annual 1994-	NIFES, annual; SFT/NIVA, annual 1994- PINRO, rarely-1994	IMR, every 3rd year 2003- , NIFES, annual 2007-; SFT/NIVA, annual 1994- PINRO annual-1994	-	NPI	SFT/NILU annual
Chlordan	PINRO, annual 1994-	PINRO, annual 1994-	PINRO, rarely-1994-	PINRO, annual 1994-			
Phenols		Sevmorgeo annual, 2005-					
Other chlorinated pesticides	IMR, irregular		NIFES, annual	IMR, every 3rd year 2003- , NIFES, annual 2007-	-	NPI	
TBT	NGU, annual 2006- SFT/NIVA, every 10-12 yers 1994-	-	SFT/NIVA, annual 1994-	SFT/NIVA, annual 1994-	-	NPI	
BFR	Various institutions, occasional	-	SFT/NIVA, annual; NIFES, annual	SFT/NIVA, annual 2007- NIFES, annual;	-	Various institutions, occasional	SFT/NILU annual
PFC	Various institutions, occasional	-	Various institutions, occasional	Various institutions, occasional	-	Various institutions, occasional	SFT/NILU annual
Radionuclides	IMR, annual 1999-; NRPA, every 3rd year 1999- Sevmorgeo annual 2005-	IMR, annual 1999- NRPA, monthly, annually, every 3rd year 1999- Sevmorgeo annual 2005-	NRPA, occasional	IMR, annual 1999- NRPA, every 3rd year 1999-	NRPA, annual 1999- IMR, irregular	NRPA, irregular	NRPA, weekly 1990-

4 Current and expected state of the ecosystem

This chapter focus on the current and future status of the Barents Sea ecosystem. Current status for abiotic and biotic components are described in chapters 4.2 and 4.3, respectively, by using the most recent data. In addition, expected development in the near future (approximately < 5 years) is discussed for several of the abiotic factors and biological groups. Current status of human activities and the impact each of them have on the ecosystem is dealt with in chapter 4.4. A short summary of the main issues in subchapter 4.2-4.4 is given in chapter 4.1. Overall conclusions about current status and expected development in the near future are drawn in chapter 4.5. The discussion here focuses particularly on the aspects of the status that are likely results of human impact. The last subchapter takes a different approach than subchapters 4.1 - 4.5 by focusing on aspect of possible future long-term change in the Barents Sea ecosystem, such as effects of long-term climate change and ocean acidification.

4.1 Overview of state and expected situation

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Key points from the rest of chapter 4 are summarized in this section.

4.1.1 Overview of abiotic compontents

4.1.1.1 Overview of climate

The distinctive feature of the atmospheric circulation was an intensification of the Arctic anticyclone during spring and summer, which caused a southward shift of Atlantic cyclone tracks and prevalence of northerly and easterly winds over the Barents Sea.

The Atlantic Water temperature was higher than the average throughout the year of 2008, but colder than in the previous two years. The positive temperature anomalies gradually decreased from January-March to August-September, and then increased again during the autumn. In the coastal waters, negative temperature anomalies (the coldest for the last 10 years) were registered in September 2008. Throughout the year, the ice cover was below average, but still more than in 2007. The Atlantic water inflow in 2008 was much as in 2007: Moderate during winter, strongly decreased during spring and close to the average in early summer.

The Atlantic Water temperature in 2009 is expected to decrease from the very warm year of 2008, and further decrease towards average temperatures in 2010.In the same period the ice cover is expected to increase although it is likely to still be below average.

4.1.2 Overview of biotic components

4.1.2.1 Overview of phytoplankton and zooplankton

The spring bloom of phytoplankton at the Bear Island transect in 2008 was within the "normal" period of the spring bloom and started in the end of April. In addition to available nutrients the onset of the spring bloom depends heavily on factors such as stratification and light.

In 2008 the average zooplankton biomass was below the long-term mean. However, the average value for 2008 is based on fewer stations than covered the year before. In the Russian sector alone the average biomass in 2008 was considerably higher than what was observed in the Norwegian part of the Barents Sea. Reductions in zooplankton biomass in the center and western parts of the area were probably influenced by oceanographic factors and predation from fish, in particular capelin.

The aggregations of juvenile euphausiids found north of 78ºN in 2008 and high biomass of krill in the north-west and the south-eastern parts of the Barents Sea, support the notion that krill is expanding their distributional range in the Barents Sea.

The high zooplankton biomass core found in the Russian sector seems to be beyond reach of the polar cod, which has its main distribution further north. This is an additional feature suggesting a higher zooplankton survival rate in this particular eastern region, probably favouring a high overwintering stock that could support a high local production in 2009.

4.1.2.2 Overwiew of benthos

Several species of bottom dwellers are found anchored or crawling on the sea bottom, or living in between already existing communities of benthic animals creating a multi-species habitat. By-catch in bottom trawl indicates that the current distribution of megabenthos in the Barents Sea is highly variable from area to area, with "hot spots" at the Tromsø Flake (mainly sponges), on the Spitsbergen Bank (large variety of conspicuous epifauna species), the Olga Strait (large aggregations of brittle stars), Goose Bank and Novaya Zemlya Bank. When by-catch data are compared with grab data, the fluctuation over time was similar. Long term changes in benthos biomass through the 20th century have been linked to temperature and intensity of bottom trawling, but the role of these factors for biomass variation in recent years cannot be identified with any fair certainty.

4.1.2.3 Overview of shellfish

The indices of stock size of Northern shrimp (*Pandalus borealis*) have increased from 2004 to 2006, but decreased again from 2006 to 2008. Given the high probability of the stock being considerably above B_{msy}, risk of stock biomass falling below this optimum level in the near future is low.

The commercial stock of Iceland scallop in the Russian sector has been decreasing since 2001. The Iceland scallops stocks in the Svalbard area has not been surveyed since 2006, but the status of these stocks are probably not changed since there have been no fishery in the area.

The snow crab (*Chionoecetes opilio)* is recorded as bycatch in trawl and gillnet fishery in Norwegian waters with an increasing frequency. The main part of the catches is in the northern part of the Barents Sea and in the Svalbard Conservation zone. In the last few years an increased portion of small crabs was observed in the eastern sea.

In August-September 2008, the densest concentrations of red king crabs **(***Paralithodes camtschaticus***)**, more than 500 ind/sq.km, were observed in the southeastern part of the Barents Sea. The official catch of red-king crab in 2008 accounted for 2,500,000 individuals.

4.1.2.4 Overview of fish

Based on the most recent estimates of spawning stock biomass, ICES classifies the stocks of cod and haddock to have full reproductive capacity and being harvested sustainably.

Signs of improved recruitment of redfish are now seen in the Barents Sea. In this regard, it is of vital importance that the juvenile age groups be given the strongest protection from being caught as bycatch in any fishery.

There is at present no accepted assessment for Greenland halibut, mainly due to age-reading problems and lack of contrast in the data. However, indications from fishery independent surveys are that the stock has increased in recent years.

Based on the most recent estimates of SSB and recruitment ICES classifies the stock of capelin as having full reproductive capacity. The stock is increasing and observations during the international 0-group survey in August-September 2008 indicated that the 2008 year class is strong.

Based on the most recent estimates of SSB and fishing mortality of herring, ICES classifies the stock as having full reproductive capacity and being harvested sustainably. Preliminary indications show that the year classes 2005-2008 are below average. Therefore the abundance of herring in the Barents Sea is believed to be at a relatively low level in 2009.

The polar cod stock is presently at a high level. The natural mortality rate in this stock seems to be very high, and this is explained by the importance of polar cod as prey for cod and different stocks of seals.

In autumn 2008, the acoustic abundance of blue whiting was estimated to 0.1 million tonnes, which is much lower than in 2007. Thus, the abundance of blue whiting in the Barents Sea is expected to stay at a low level until the recruitment to the stock increases again.

ICES classifies the saithe stock as having full reproductive capacity and harvested sustainable.

4.1.2.5 Overview of marine mammals

Population data are scarce for many species of marine mammals in the Barents Sea, making it difficult to identify population trends and their underlying causes.

Hooded and harp seals are both found in the West Ice and harp seals also breed in the White Sea. The most recent estimate for the West-ice group of harps seals is ~750 000 (2008) and the population is thought to be stable or increasing. Recently, pup production in the White Sea harp seal population has been in decline, dropping from over 300,000 in 1998-2003 to 123,000 in 2008. Current (2007) abundance of the West Ice hooded seal stock was estimated to be ~82 000 animals, which is very low compared with historic numbers. The declining trends seen in both harp and hooded seal populations are probably caused by reductions in sea ice and other ecosystem changes related to climate warming.

Ringed seal reproduction has been negatively impacted by recent poor ice years in Svalbard (2006, 2007 and 2008), and the poor pup production is bound to cause declines in the adult population, with a time lag of a few years. For polar bears, population trends in the Barents Sea are unknown, but declines are expected in the coming decades. Walruses are thought to be increasing from the depressed conditions caused by hunting in the past, but the total population size of the whole Barents Sea is unknown as Russian areas have never been surveyed.

The white whale, or beluga whale, is the most numerous of the three resident, ice-associated arctic whales (white whale, narwhal and bowhead whale) in the Barents Sea. Their numbers have not been assessed, but this species likely numbers in the tens of thousands in the Svalbard/Barents Sea area. Narwhal have not been censused, but are certainly less numerous than white whales. The present number of bowheads belonging to the Svalbard stock is not known, but is presumably only in the tens or at most, in the low hundreds.

No systematic assessments have been conducted for bearded seals, but it probably numbers in the hundreds of thousands in the Arctic and certainly in the thousands in the Barents Sea,
Among the toothed whales, the long-finned pilot whale, the killer whale, the northern bottlenose whale and the sperm whale are summer visitors to the Barents Sea. The minke whale is the most numerous of the baleen whales that frequent the Barents Sea on a seasonal basis. Fin whales and humpback whales are second and third most abundant. In late summer in the northern Barents Sea, the distribution of baleen whales seems to be tightly linked to the capelin foraging migrations. Fin, humpback and minke whales generally occur along the northern front of the capelin migrations, avoiding areas with high capelin density.

The Norwegian coastal stock of harbour seals are subject to hunting or fishery related mortality, and current levels of mortality are thought to be unsustainable. Grey seals in the Norwegian part of the Barents Sea are subject to hunting levels that are not sustainable. Harbour porpoises are subject to by-catch in fisheries, and in order to sustain current levels of by-catch, immigration from outside the Barents sea is required.

4.1.2.6 Overview of seabirds

Altogether 15 species of seabirds were monitored in 2008 at 18 different locations in the western and southern Barents Sea and the White Sea. The 2008 season was characterized by decrease in the breeding populations of several species in the western Barents Sea, especially along the mainland coast of Norway, from Nordkapp and westwards. The species that were most severely affected are fulmar, black-legged kittiwake, razorbill and common guillemot. The low number of birds attending both Norwegian and Russian colonies in 2008 do not only reflect low adult survival between years, but may also have been the result of poor environmental conditions with reduced body condition and low colony attendance as the result. In contrast, seabird populations in the eastern and northern parts of the Barents Sea are generally stable or increasing.

4.1.2.7 Overview of rare and threatened species

The actual area is inhabited by 28 fish species which are either on the Global Red List (8 species), or on the Norwegian Red List (25 species). Among these 13 is DD species, i.e. no scaled evaluation can be done because of lack of knowledge, but the species would probably be on the red list if adequate information had been available.

Barents Sea is inhabited by 26 species (taxons and populations) of sea mammals. Among these, 11 species are included in the International Red Book, 15 are included in The Red Book of Russian Federation (2001) and 9 are in the endangered-species list of Norway.

Among more than 30 seabird species breeding and wintering in the Barents Sea region, there are 7 Red-listed species including two from the global list (IUCN, 2008), 6 from Norwegian Red List and 3 from the Red Data Book of the Russian Federation. Besides, there are 4 more species listed in the Annex to the Red Data Book of the Russian Federation that are of concern.

4.1.2.8 Overview of introduced species

These organisms entered the Barents Sea both in a natural way - through the expansion of habitat due to global warming, and as a result of human activities, related to the intentional or accidental introduction of alien organisms. There are currently 15 species considered introduced and invasive.

At present, studies related to the invasive species are mainly focused on two kinds of crabs: Red king crab (*Paralithodes camtschaticus*) and Snow crab (*Chionoecetes opilio*), that are of economic importance. Scientific information regarding other invasive species is fragmentary and requires further research.

4.1.3 Overview of human activities/impact

4.1.3.1 Overview of fisheries

Fisheries are meant to influence the ecosystem by removing sustainable quantities of fish as food for humans. The fishery is, however, not considered sustainable if it impairs the recruitment of the fish stocks. Single species management often focuses on measuring the status of the fishery in relation to benchmarks called biological reference points (BRPs). The harvest rate and fishing pattern should hence fit with these biological requirements.

The exploitation of Northeast Arctic cod, haddock and saithe since 2000 have been sustainable and has not influenced the ecosystem negatively by impairing the recruitment. It can be concluded that the current fishery of golden redfish is too high and may have a negative influence on the ecosystem and the stock itself. After many years of overexploitation of the Greenland halibut stock the current exploitation seems to be sustainable and hence not influencing the ecosystem negatively.

The level of discarding in the fisheries is not known, and no discards are accounted for in the assessments. Discarding is known to be a (varying) problem in specimens close to, but below the minimum landing size. The lack of discard estimates leads to less precise and accurate stock assessments, and the influence of the fishery on the ecosystem is hence less understood.
In order to conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. In general, the response of benthic organisms to disturbance differs with substrate, depth, gear, and type of organism. The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. Barents Sea hard bottom substrata, with associated attached large epifauna should therefore be identified. Effects on soft bottom have been less studied, and consequently there are large uncertainties associated with what any effects of fisheries on these habitats might be.

Lost gears such as gillnets may continue to fish for a long time (ghost fishing). The catch efficiency of lost gillnets has been examined for some species and areas, but at present no estimate of the total effect is available. Other types of fishery-induced mortality include burst net, and mortality caused by contact with active fishing gear, such as escape mortality.

Work is currently going on jointly between Norway and Russia, exploring the possibility of using pelagic trawls when targeting demersal fish. The purpose is to avoid impact on bottom fauna and to reduce the mixture of other species. It will be mandatory to use sorting grids to avoid catches of undersized fish.

4.1.3.2 Overview of pollution

The Barents Sea is to a large extent a clean environment. Monitoring results indicate generally low levels of contaminants, with some exceptions. Persistent organic pollutants (POPs) that accumulate to high levels in organisms at the top of the food-chain are of special concern.

Data from Zeppelin Mountain in Ny-Ålesund has shown that the concentration of long-range transported substances like PCB and PAH has had a steady decrease since the beginning of the 90-ies, but increased concentrations in air were observed in 2007. These increasing concentration levels may be explained by increased evaporation of previously deposited HCB from the open ocean along the western coast of Spitsbergen (Svalbard, Norway) which has been ice-free during the past four years, including the winter seasons (2005-2008).

The levels of persistent organic pollutants in polar bears at Svalbard and Franz Josef Land are above the limits for effects on hormone and immune system. PCB has been found in especially high concentrations (AMAP 2004). The trend is increased levels of PCB from the western populations to the eastern populations, probably due to a larger long range transport of PCB substances from Europe to Svalbard and the Barents Sea area. Recent studies have also found newer contaminants like BFH and PFC in polar bears in the Svalbard region.

For most of the monitored substances in fish and shellfish in the Barents Sea the levels are well below the limits values for human consumption.

The issue of present and potential radioactive contamination in the Barents Sea has received considerable attention in recent years. At present time a general tendency to decrease is indicated for all the radionuclides.

4.1.3.3 Overview of oil and gas activities

Results from environmental monitoring have so far shown no effects from operational discharges into the water column and there has been no significant accidental discharge of oil or chemicals in the Barents Sea so far.

The greatest environmental risk 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, the Polar front, Pechora Sea with great amounts of sensitive species and areas.

It is expected that two new wells will be drilled in the Norwegian and Russian sectors of the Barents Sea in 2009. For transportation of gas condensate, there are plans to build underwater pipeline that will lead to significant disturbance of the bottom sediments and coastal line.

The environmental risk, or the risk that an oil spill will affect seabirds, the supra-littoral zone or other elements of the ecosystem, depends on a number of factors. The most important of these are the probability of an oil spill, the magnitude of a particular spill, its geographical position in relation to vulnerable areas and resources, when it occurs in relation to periods when vulnerability to oil spill is particular high, and the spill trajectory.

4.1.3.4 Overview of maritime transport

The routine discharges to the sea from shipping that have most impact on the environment are operational discharges of oil and the release of organotin compounds from anti-fouling systems.

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 shipping traffic.

4.1.3.5 Overveiw of other human impact

The arctic region is under steadily increasing pressure from tourism, but little is known about overall impact in the Barents Sea.

Aquaculture may affect the ecosystem when farmed fish escape and interact with native fish, through spread of pathogens and through pollution. The total impact from such effects in the Barents Sea today is not known.

4.2 Abiotic components

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4.2.1 Meteorological conditions

4.2.1.1 Atmospheric pressure and wind field

In winter 2007/2008, a low-pressure trough related to the Icelandic Low dominated the northern North Atlantic, the Nordic Seas and stretched deep into the Barents Sea (Figure 4.2.1). Large negative air pressure anomalies (-4 - -5 mb) were spread over the Norwegian and northern Barents Seas. The southern part of the Barents Sea were dominated by a bit smaller negative anomalies (-3 - -4 mb). Such an air pressure pattern would have strengthened the southwesterly winds and increased transport of warm air and water in the southern Barents Sea. Relatively strong southwesterly winds prevailed over the southern part of the sea, while light easterlies dominated the northern Barents Sea. In summer 2008, a low-pressure trough stretched over terrestrial area from the western Siberia to Scandinavia and further into the North Atlantic with maximum negative air pressure anomaly (-4 - -5 mb) centered over the British Isles. Horizontal air pressure contrasts were considerably smaller than in winter, and weak easterly and northeasterly winds prevailed over the eastern Barents Sea (Figure 4.2.1). Stronger northerly winds dominated the Barents Sea Opening and Bear Island – Svalbard area.

4.2.1.2 Air temperatures

Air temperature data were taken from http://nomad2.ncep.noaa.gov and averaged over the western (70-76°N, 15-35°E) and eastern (69-77ºN, 35-55ºE) parts of the sea. During winter and spring, the air temperature was warmer than normal, with maximum positive anomalies (6.0-7.0 °C) in the eastern Barents Sea in February and March. In April-September, the air temperature was generally close to the long-term means, with prevalence of small negative anomalies (<0.5 °C). In October-November, over most of the sea, the air temperature was, on average, 0.5-1.0 °C higher than normal; and in December, positive anomalies increased to 3.0-4.0 °C (Figure 4.2.2).

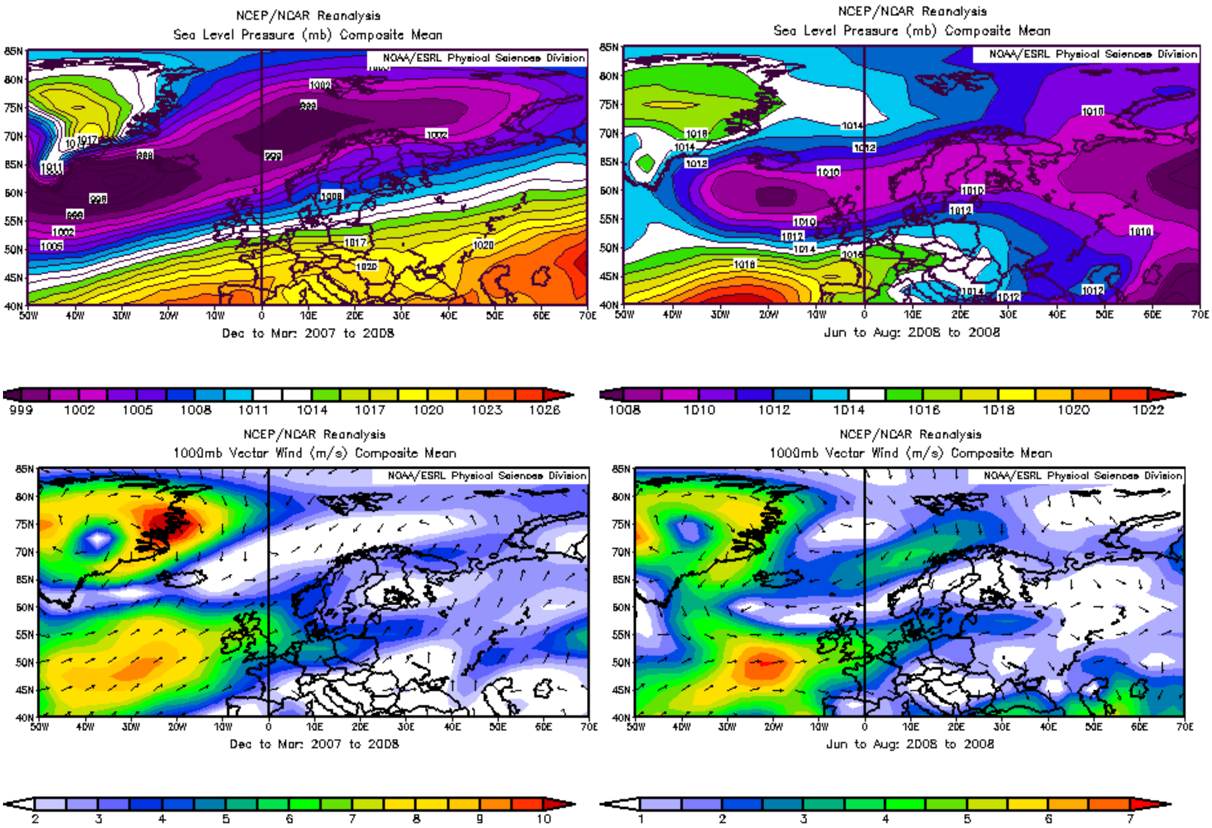

Figure 4.2.1. Sea level pressure (upper) and wind vectors (lower) in December-March 2007-2008 (left plates) and. June-August 2008 (right plates).

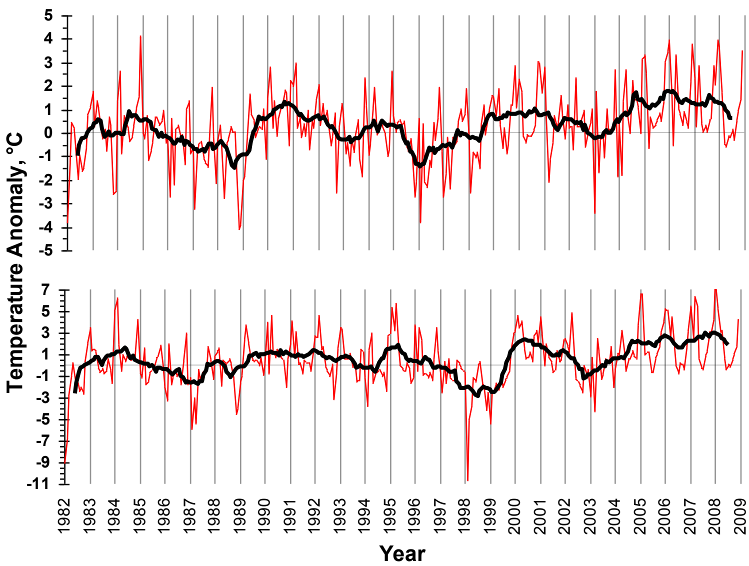

Figure 4.2.2. Air temperature anomalies over the western (upper) and eastern (lower) Barents Sea in 1982-2008.

Table 4.2.1 summarizes air temperature anomalies at some meteorological stations at the western and southern Barents Sea during the period from late 2007 through 2008. In winter 2007/2008, air temperature over the region was considerably warmer-than-normal (by 1.5-5.0 °C), with highest anomalies at the Svalbard airport, Kanin Nos (6.2 °C in January 2008) and Murmansk (7.1 °C in December 2007). Large positive anomalies alternated with colder-than-normal temperature at all stations but Vardø in March. During spring and summer temperature anomalies were predominantly negative. In September, colder-than-normal temperature alternated with positive anomalies, which rose again to 2.5-5.1 °C in December. Mean annual air temperature in 2008 was warmer-than-average by 0.2-1.8 °C. Mean annual air temperatures in 2008 were colder than in 2007 by 0.3-0.7 °C at Bear Island, Tromsø, Vardø and Murmansk, while at the southeastern (Kanin Nos) and northwestern (Svalbard airport) stations they were colder than the previous year by 1.0 and 2.1 °C correspondingly.

Table 4.2.1. Mean air temperature anomalies at weather stations around the Barents Sea in December 2007-December 2008, yearly mean anomaly in 2008, maximum anomalies and years when they were observed.

	Year/Month														
	2007	**2008**												**2008**	
Station	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**mean**	**Max/Year**
Svalbard airport	3.7	6.2	5.3	-1.2	-0.2	1.3	0.5	-0.2	-0.4	2.3	-0.5	0.1	3.8	1.1	4.3 2006
Bear Island	5.3	5.7	4.3	-0.4	0.3	1.2	0.5	0.2	-0.1	1.7	0.4	2.0	5.1	1.8	2.9 2006
Tromsø	4.0	1.6	1.8	-1.4	-0.9	-0.8	-1.0	1.8	-1.1	0.0	0.9	0.4	2.5	0.2	1.5 1938
Vardø	4.1	2.7	2.2	0.2	-0.1	0.1	-0.1	-0.5	-1.1	0.3	1.4	1.2	3.3	0.9	1.5 1937/2005
Murmansk	7.1	5.2	3.3	-1.3	-0.6	-0.7	-0.2	-0.8	-1.9	-0.4	1.8	1.4	4.4	1.1	2.0 2005
Kanin Nos	4.4	6.2	3.4	-0.4	0.3	-0.4	0.2	0.2	-0.2	0.1	1.6	1.5	4.7	1.3	2.5 1937

4.2.2 Oceanographic conditions

4.2.2.1 Temperature at the surface, 100 m and in the bottom layer

Sea surface temperature (SST) data were taken from http://iridl.ldeo.columbia.edu and averaged over the Bear Island – Svalbard area (74-79ºN, 08-25ºE), central (71-74ºN, 20-40ºE) and southeastern Barents Sea (69-73ºN, 42-55ºE). The SST shows much of the same variations as the air temperatures. During winter, over most of the Barents Sea, SST was higher-than-normal, with maximum anomalies of 1.2-1.4 °C in the eastern areas. During spring, positive anomalies of SST decreased to 0.3-0.7 °C in the eastern Barents Sea; whereas negative anomalies of SST (0.2-0.3 °C) dominated in the western sea. During summer and autumn, SST anomalies decreased in most of the Barents Sea; on the whole, SST was near normal, with small (0.2-0.4 °C) negative anomalies. During October-December, positive anomalies of SST were observed in most of the sea; maximum anomalies (up to 1.0 °C) were found in the eastern areas (Figure 4.2.3).

The time series from the coastal waters at the fixed station Ingøy confirm the pattern from the SST; during the winter of 2007-2008 the surface temperature were above the long-term mean, in spring 2008 they decreased towards the long-term mean in the summer, while in fall 2008 and early winter 2009 they were above the long-term mean (Figure 4.2.4). The same signal took place in the deeper waters (at 250 m), but the decrease occurred somewhat later in summer and was stronger. The fall of 2008 was colder than the 2 years before, particularly at depth, but from December 2008 the temperatures were again above the long-term mean. However, they are lower than during the last 3 winters.

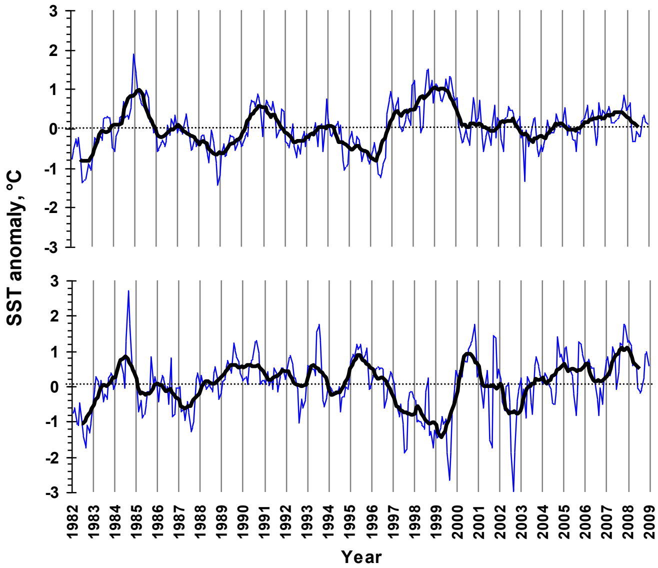

Figure 4.2.3. Sea surface temperature anomalies in the western (upper) and eastern (lower) Barents Sea in 1982-2008.

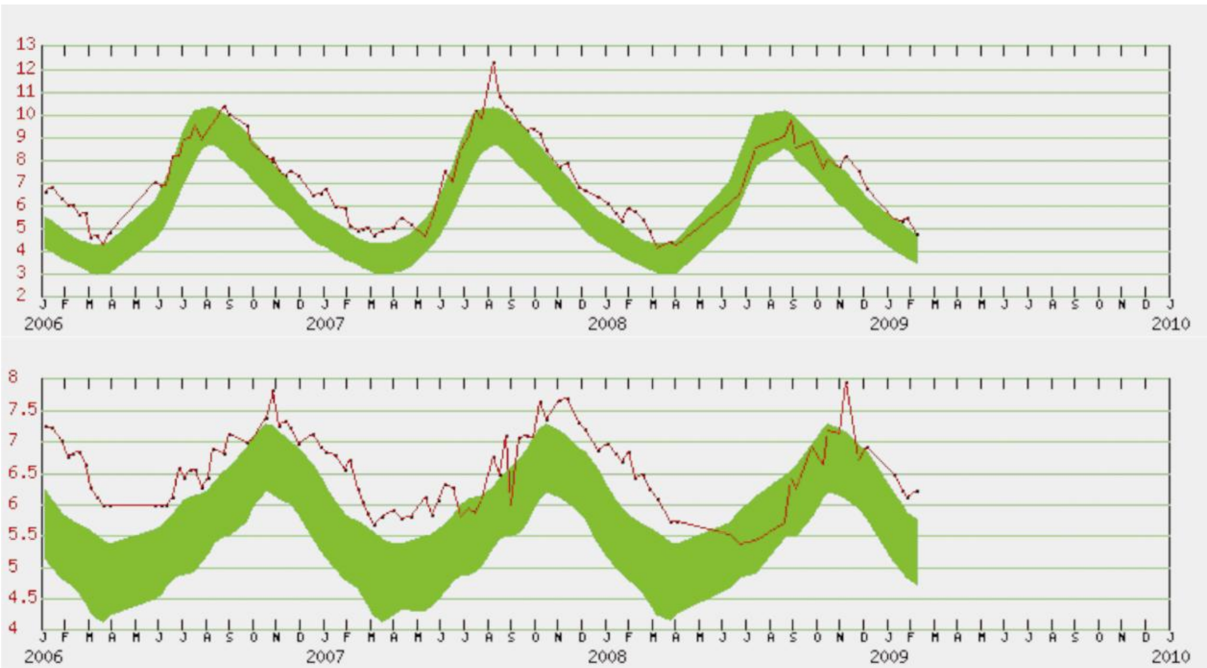

Figure 4.2.4. Monthly mean temperature at 1 m and 250 m depth at the fixed station Ingøy, northern Norway, situated in the Coastal Current at the entrance to the Barents Sea. Vertical axis is temperatures (oC) and horizontal axis is month. The green areas are the long-term mean for the period 1936-1944 and 1968-1993 +/- one standard deviation and represent the typical variations.

Looking at the overall temperature field in 100 m depth in August-September 2008, the temperatures were above the long-term mean in most of the Barents Sea (Figure 4.2.5). The highest anomalies were observed in the eastern parts, with anomalies of 1.0-1.5 °C. In the southwestern parts the temperatures in the inflowing Atlantic Waters were 0.5 °C above the long-term mean while the Coastal Waters was 0.5-1.0 °C below. Compared to 2007 the temperatures during summer were lower except in the northeastern areas.

The temperature in the bottom layer in August-September 2008 corresponded to the temperatures of warm and anomalous warm years for most of the Barents Sea, and was close to those of 2007. Positive temperature anomalies were, on average, 0.5-1.5 °C. On the whole, the eastern Barents Sea was warmer than the rest of the sea (Figure 4.2.6).

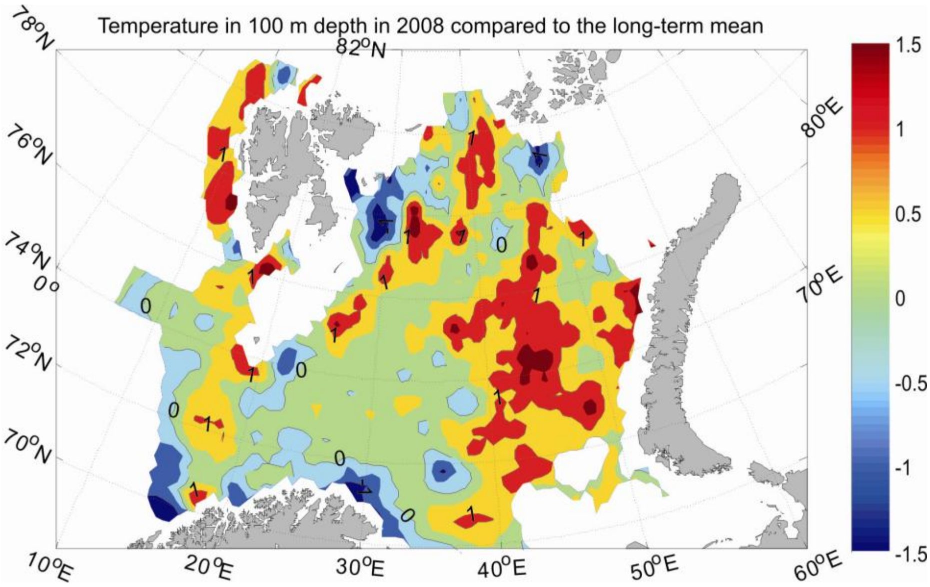

Figure 4.2.5. Temperature anomalies at 100 m depth in the Barents Sea in August-September 2008 (Anon., 2009).

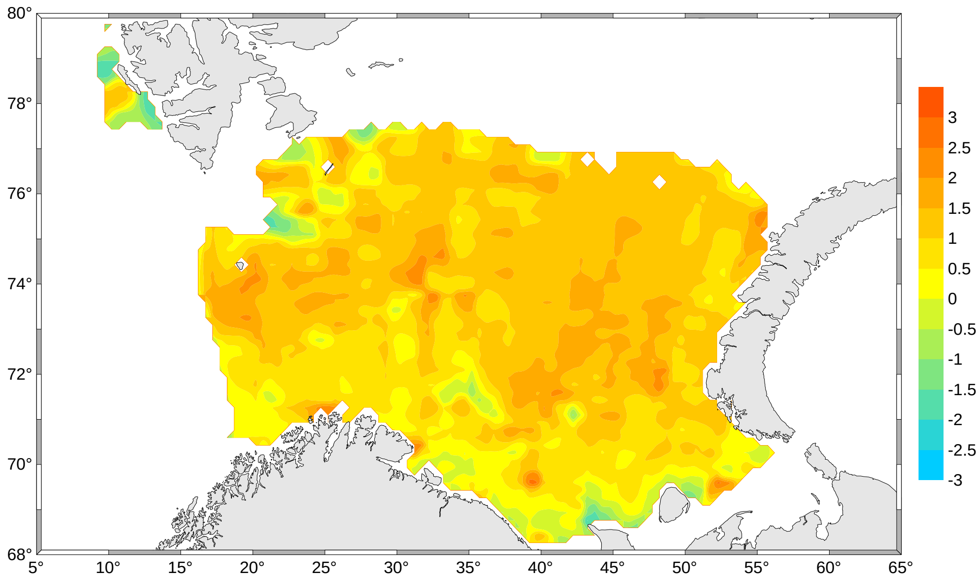

Figure 4.2.6. Bottom temperature anomalies in the Barents Sea in August-September 2008 (Anon., 2009).

4.2.2.2 Temperature and salinity in the standard sections

The Fugløya-Bear Island Section, which capture all the Atlantic Water entering the Barents Sea from south-west, showed temperatures of 0.8-1.0 °C above the long-term mean in early 2008 (Figure 4.2.7). Further east along the 31°13' E longitude, at the Vardø-North Section, the temperature during late winter was 1.5 °C above the long-term mean, which is an all time high since the time series started in 1977. The high temperatures were due to higher-than-normal temperatures upstream in the Norwegian Sea in combination with less atmospheric cooling than usual because of the high air temperatures during winter. Due to low air temperatures in spring in combination with weak Atlantic inflow, the ordinary seasonal temperature increase during spring was lower-than-normal, particularly in the south-western Barents Sea, and in August 2008 the temperature in south-west was only 0.5 °C above the long-term mean (Figure 4.2.7). The strong temperature decrease during the year, caused 2008 as a whole to be colder than the previous two years even though it started out with a new record-high temperature. The salinity variations are similar to those in temperature, and the salinity is still high but decreasing since 2006.

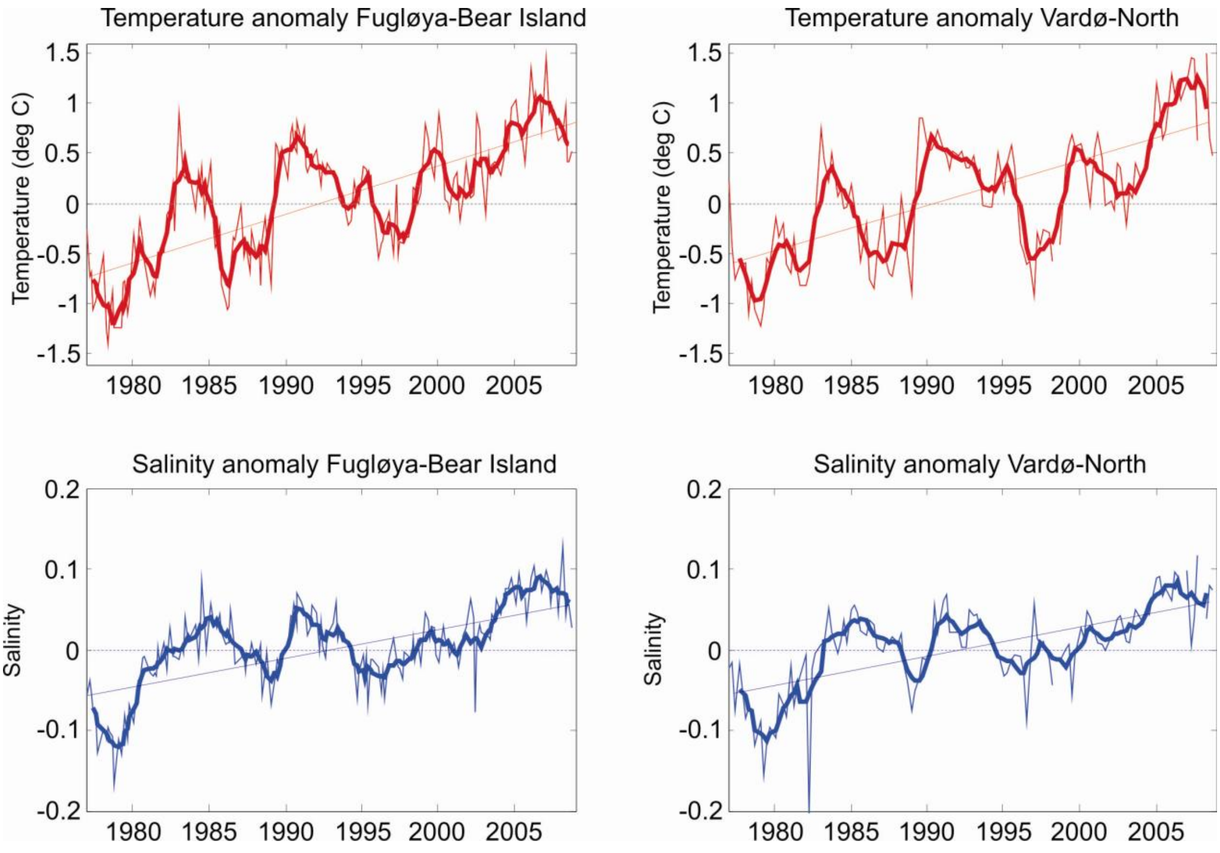

Figure 4.2.7. Temperature (upper) and salinity (lower) anomalies in the 50-200 m layer of the Fugløya-Bear Island Section (left plates) and Vardø-N Section (right plates).

According to the observations along the Kola Section, which was made 9 times in 2008, sea temperature in the active layer (0-200 m) of the southern Barents Sea was higher than the long-term mean during most of the year (Figure 4.2.8). At the beginning of the year, the weaker-than-usual seasonal cooling caused an increase in positive temperature anomalies in the Atlantic Waters compared to December. The temperature anomalies exceeded 1.0 °C through April, and in separate months they reached maximum for the period from 1951 to the present. During spring and summer, easterly and norteasterly winds prevailed and the water temperature anomalies were decreasing in most of the surveyed area. In August-September temperature in the Murman Current was near normal and the temperature anomalies did not exceeded 0.2 °C (Figure 4.2.8). In the coastal waters, negative temperature anomalies were registered and such cold anomalies have not been observed there in September for the last 10 years. At the end of the year, the weaker-than-usual seasonal cooling of the surface layer caused an increase in the temperature anomalies compared with the second half of September. Compared to the previous year, the water temperature was, on average, 0.3-0.9 °C lower in most of the water column both in the Murman Current and coastal waters (Figure 4.2.8).

In the southern Barents Sea in 2008, water salinity was typical for warm years. Negative salinity anomalies were observed during winter; in the second half of the year, some increase in salinity anomalies took place (Figure 4.2.8).

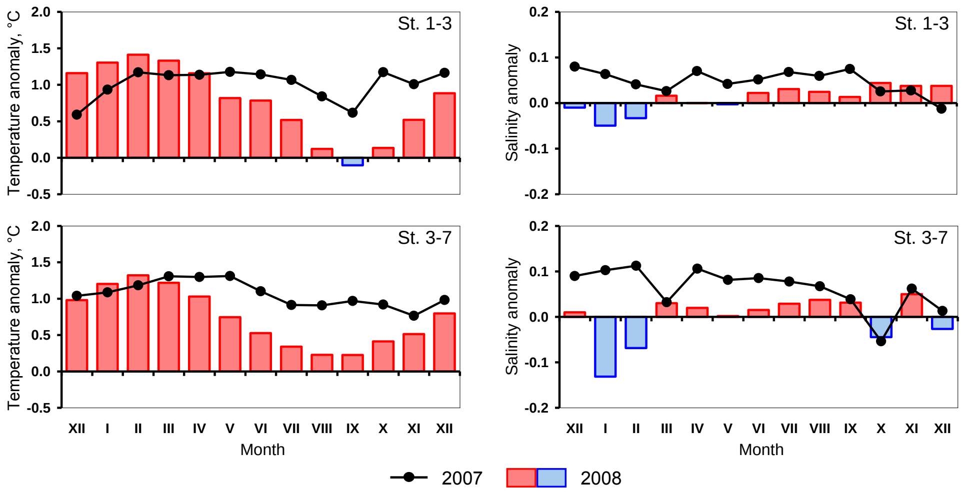

Figure 4.2.8. Monthly mean temperature (left) and salinity (right) anomalies in the 0-200 m layer of the Kola Section in 2007 and 2008. St. 1-3 – coastal waters, St. 3-7 – Murman Current (Anon., 2009).

On the whole, the annual mean temperature in the upper 200 m layer of the Kola Section was in 2008 typical for anomalous warm years, and lower than in 2007 (Figure 4.2.9). Annual mean salinity in the 0-200 m layer of the section was near normal, and also lower than in 2007.

In the North Cape - Bear Island Section, the observations were made in February, April, August and October. Positive anomalies of temperature in the 0-200 m layer of the North Cape Current decreased from 1.3 ºC in February to 0.8 ºC in April and further to 0.4 ºC in August. In October, an increase in positive temperature anomalies (up to 0.6 °C) was observed.

In 2008, the section Bear Island - West (along 74º30'N) was occupied 3 times. Temperature in the 0-200 m layer of the eastern branch of the Norwegian Atlantic Current (74º30'N, 13º30'-15º55'E) was significantly warmer-than-normal. Positive temperature anomalies decreased from 1.3 °C in March to 0.5 °C in August, and then increased to 1.2 °C in November.

During 2008, the section Bear Island - East (along 74º30'N) was made 4 times. Temperature in the 0-200 m layer of the northern branch of the North Cape Current (74º30'N, 26º50'-31º20'E) was significantly higher than the long-term average, with the maximum positive anomalies (1.1-1.9 ºC) registered in February, March and April. By October, positive temperature anomalies decreased to 0.5 °C.

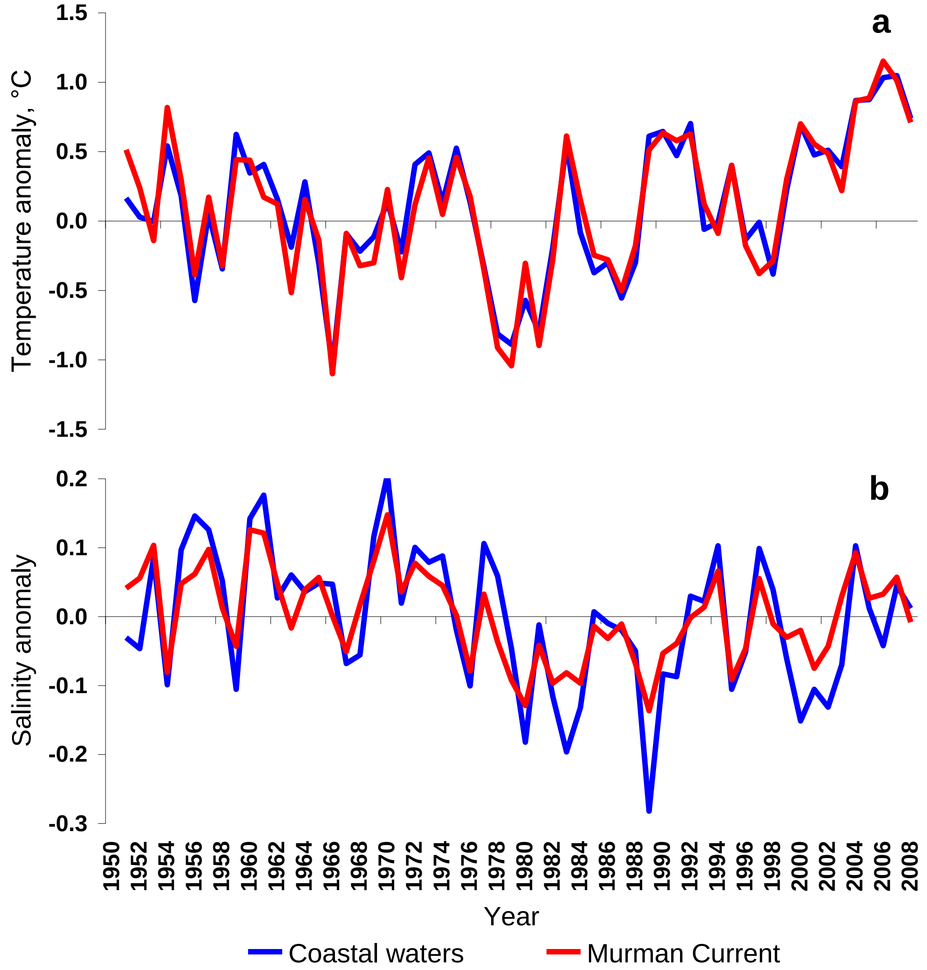

Figure 4.2.9. Mean annual temperature (a) and salinity (b) anomalies in the 0-200 m of the Kola Section in 1951-2008. Coastal waters – St. 1-3, Murman Current – St. 3-7 (Anon., 2009).

In the Kanin Section (along 43º15'E) in the eastern Barents Sea, the observations were made in February, May, August and December. In the 0-200 m layer of the Novaya Zemlya Current (71º00'- 71º40'N, 43º15'E), positive temperature anomalies decreased from 2.1 °C in February to 1.1 °C in May, and to 0.8 °C in August. By December, the temperature anomalies increased again to 1.4 °C.

4.2.2.3 Currents and transports

The temperature and the volume flux of the inflowing Atlantic Water in the Fugløya-Bear Island Section do not always vary in phase. The temperature is mainly determined by variations upstream in the Norwegian Sea, while the volume flux to a large degree varies with the wind conditions in the western Barents Sea. The volume flux varies with periods of several years, and was significantly lower during 1997-2002 than during 2003-2006 (Figure 4.2.10). The year of 2006 was a special year as the volume flux both had a maximum (in winter 2006) and minimum (in fall 2006). Since then the inflow has been low, particularly during spring and summer. The inflow in 2008 was much as in 2007; moderate during winter followed by a strong decrease in spring. In early summer 2008 the flux was close to the average. As the observational series still only have data until summer 2008, it cannot give information about the situation in fall 2008 and early winter 2009.

There is no significant trend in the observed volume flux from 1997 to summer 2008.

Monthly wind-driven and total volume fluxes and their anomalies were calculated with a numerical model (Trofimov, 2000) for the main currents of the Barents Sea in 2008 (Figure 4.2.11).

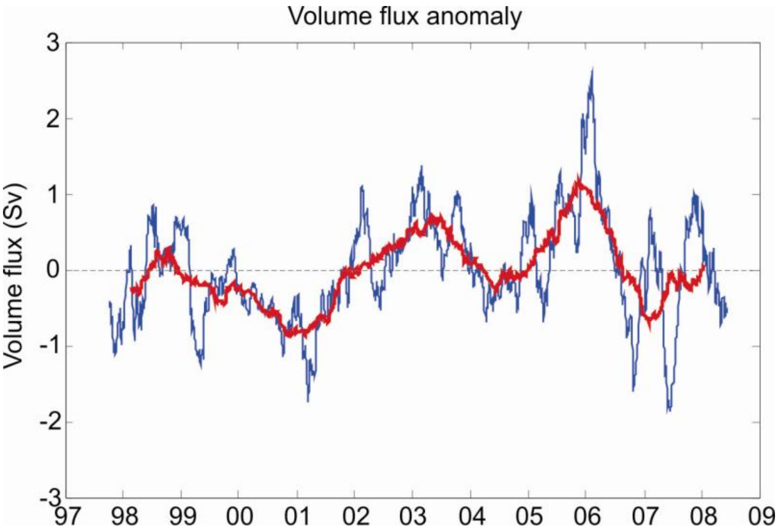

Figure 4.2.10. Observed Atlantic Water volume flux through the Fugløya-Bear Island Section estimated from current meter moorings. Three months (blue line) and 12-months (red line) running means are shown.

In 2008, on the whole, the general circulation in the Barents Sea was stronger than in 2007. In comparison with the long-term means, annual total flux values were significantly higher in the Bear Island Current, central branch of the North Cape Current and Novaya Zemlya Current. They were slightly higher in the North Cape and Murman Currents, and slightly lower in the northern branch of the North Cape Current. Throughout most of the year of 2008, total fluxes in the Novay Zemlya Current were higher than normal and than in 2007.

In 2008, on the whole, the wind-driven circulation in the Barents Sea increased the general circulation during winter, and decreased it from mid-spring through summer.

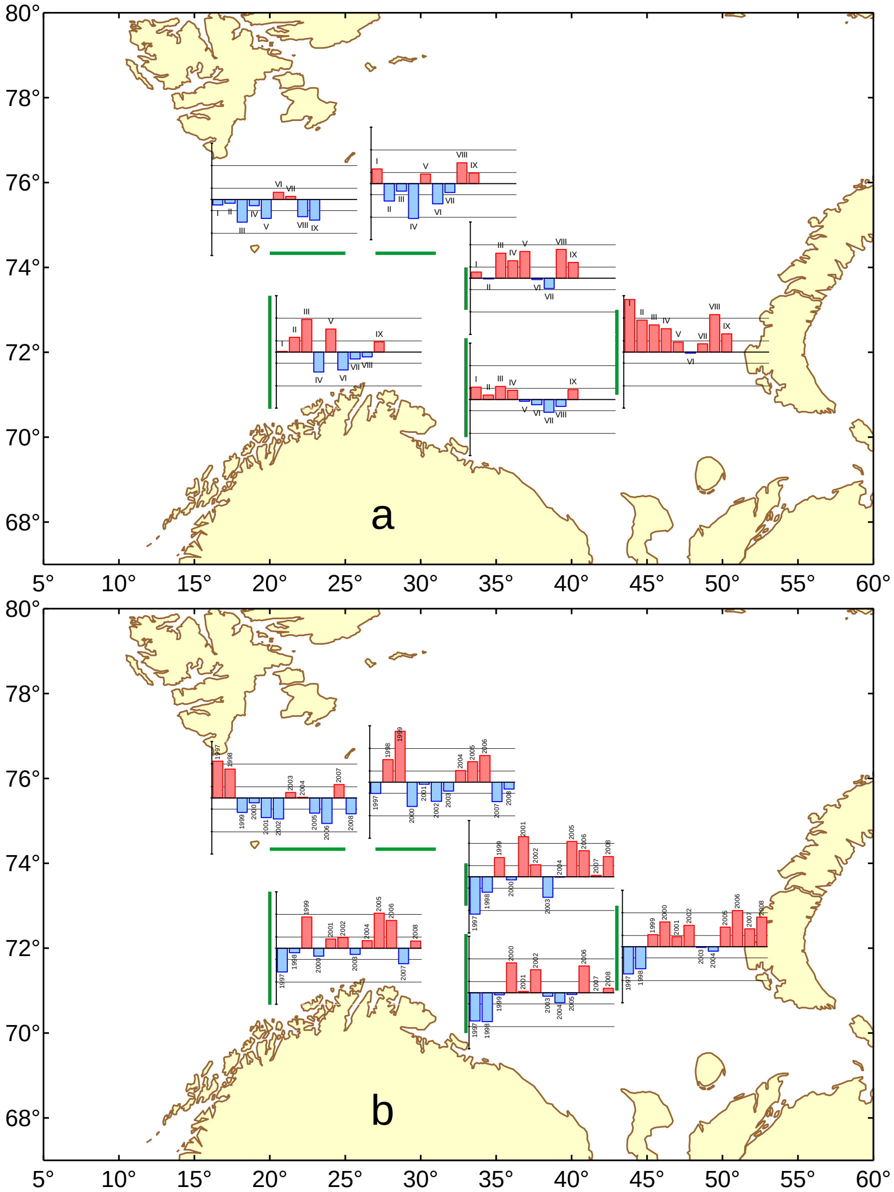

Figure 4.2.11. Monthly (a) and annual (b) total flux anomalies (Sv) in the Barents Sea in 2008 and for the period of 1997-2008 respectively (normalized by standard deviation (σ); the vertical scale range is 5σ, a vertical scale interval is 1σ).

4.2.2.4 Ice conditions

Throughout most of the year of 2008, the sea ice extent was less than normal, but more than in 2007. In comparison with the previous year, the ice coverage (expressed as a percentage of the sea area) was 2-6 % more in January-March and twice as much by June. In May, a polynya started to form south of the Franz Josef Land archipelago and in July the ice massif was finally broken. Come September, the area near Franz Josef Land was ice-free and the main ice massif was in the north-western Barents Sea near the east coast of the Spitsbergen archipelago. Ice formation started in the northernmost sea in October. By the end of the year the ice coverage of the Barents Sea was 5-12 % less than normal and 13-19 % more than in 2007 (Figure 4.2.12).

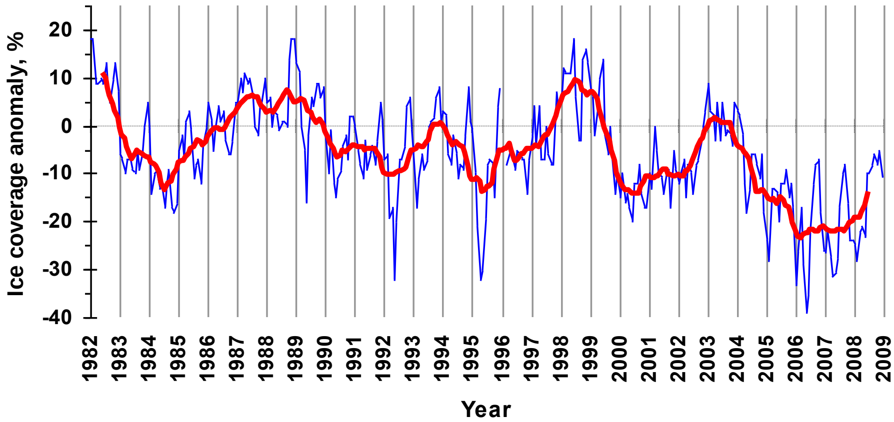

Figure 4.2.12. Anomalies of mean monthly ice extent in the Barents Sea in 1982-2008. The blue line shows monthly values, the red one – 11-month moving average values (Anon., 2009)

4.2.2.5 Chemical conditions

Since 2002, there has been a gradual increase in oxygen saturation of the bottom layers in the southern Barents Sea, – and this continued in 2008. The oxygen saturation anomaly in the bottom layer was 0.65 % during the first nine months of 2008, while during the same period in 2007 the anomaly was 0.14 % (Figure 4.2.13).

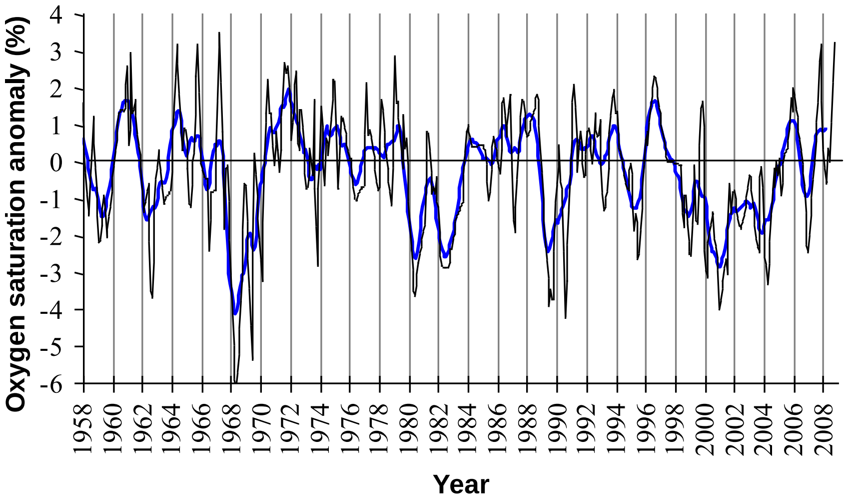

Figure 4.2.13. Monthly and annual oxygen anomalies in the bottom layer of the Kola Section in 1958-2008 (Anon., 2009).

4.2.2.6 Expected situation

The ocean has a "long memory" compared to the atmosphere, and it is therefore feasible, at least a priori, to realistically predict ocean temperature much further ahead than the typical weather forecast. The prediction is complicated by the variation being governed by processes of both external and local origin operating on different time scales. Thus, both slowly moving advective propagation and rapid barotropic responses due to large-scale changes in air pressure must be considered.

Advection may be considered a natural starting point for predicting Barents Sea temperatures, and temperature variations in the southern Norwegian Sea has often been seen 2-3 years later in the Barents Sea. In the last years this relation has been weaker than normal because the local cooling taking place in the Barents Sea during winter has been less than usual. However, as the climate of the Barents Sea has a cyclic variation of 5-7 years and most time series now show a decrease since 2006, the temperatures are expected to decrease in 2009 compared to 2008.

According to computation by a prediction model (Boitsov and Karsakov, 2005), based on harmonic analysis of the Kola Section temperature time series, the temperature of Atlantic water in the Murman Current in 2009-2010 is expected to decrease from the anomalous warm year of 2008 to the warm year of 2009, and to the normal year of 2010 (Table 4.2.2).

Table 4.2.2. Predicted temperature in the Kola Section (0-200 m), representing the southern Barents Sea.

Year	Observation 2007	Observation 2008	Prediction 2009	Prediction 2010
Temperature	4.9	4.7	4.3	4.1

It should be stressed that the predictions in this chapter are fundamentally different from the global change scenarios for 50 or even 100 years ahead (e.g. ACIA, 2005; IPCC, 2007). These long-term trend scenarios are addressed in chapter 4.6.1.1.

Due to the decreasing temperatures and the extreme ice minimum the recent years, the ice cover is expected to increase although it is likely to still be below the long-term mean.

4.3 Biotic components

4.3.1 Phytoplankton

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There is large interannual and geographical variation in the distribution and abundance of phytoplankton species with in the area. However, the main pattern in the annual succession pattern is rather stabile despite variability in abiotic factors (e.g. temperature) between the years. The starting point of the spring bloom will vary between years, a variation that in large degree is controlled by the onset of necessary stability of the water column for bloom formation. Large blooms, with exception of the spring and autumn situation, might occur some years along the coast or in the open waters of the Barents Sea.

In Norwegian waters there was not observed any large aberration in the annual succession in the phytoplankton along the fixed transect (Vardø – North and Fugløya-Bear Island) in 2008. The spring bloom started in the end of April at the Bear Island transect, within the “normal” period of the spring bloom (Figure 4.3.1).

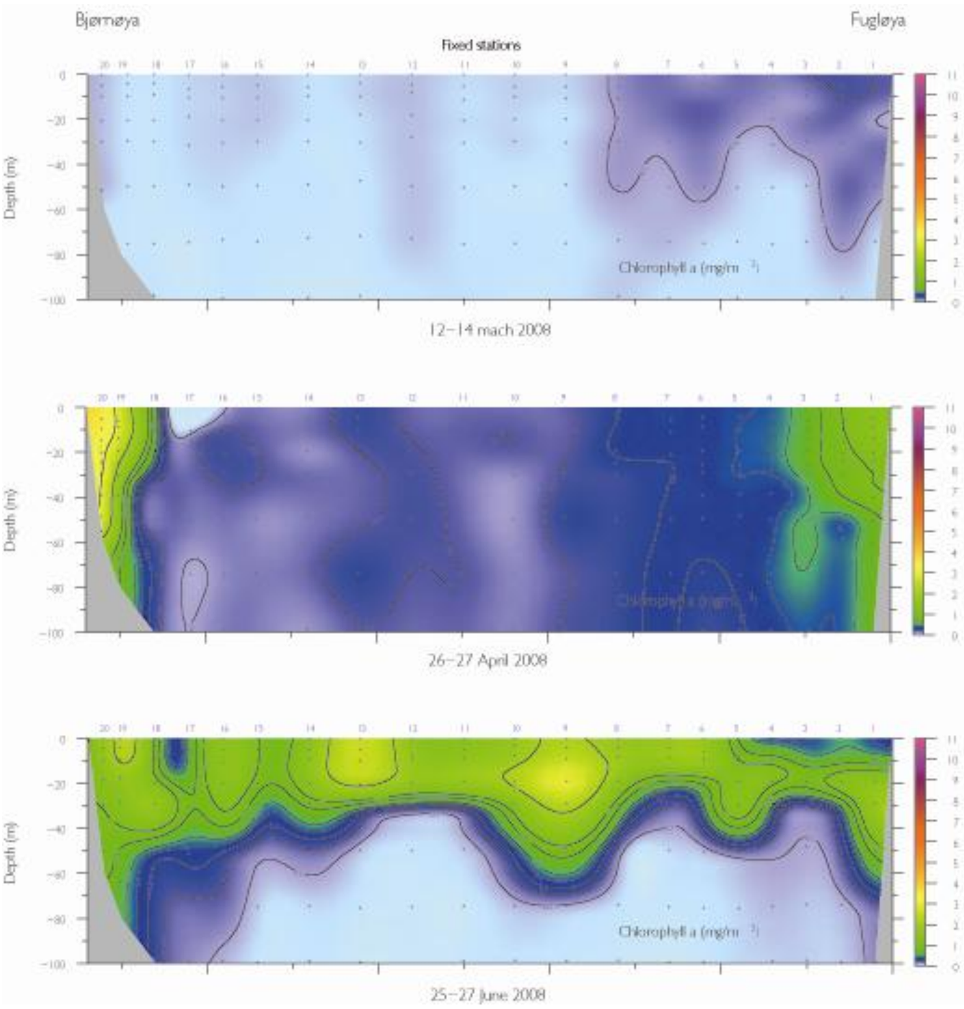

Figure 4.3.1. Chlorophyll a in the upper 100 m on the transect Fugløya–Bear Island in March, April and June

The bloom starts in the coastal waters “spreading” out into the open areas. In April the diatoms were dominating, with strain of Phaeocystis. Species within the genus Chaetoceros, especially C. socialis, and Thalassiosira nordenskioeldii was conspicuous. These species is common during the spring period. During summer the phytoplankton shows a patch distribution, with higher abundance at some station than other, also the species or groups has a more patch distribution. The phytoplankton was compound of small flagellates, dinoflagellates (naked forms, Gymnodinium and Gyrodinium), and at some stations diatoms (e.g. Leptocylindrus). As in 2007, there was observed a bloom of Emiliania huxleyi along the Norwegian coast during July to mid August. It seem like this species has become more common in this area the latest years. During autumn larger dinoflagellates, especially Ceratium spp, Dinophysis spp, and Gymnodinium spp was common along the both transects. However, at some stations, diatoms, such as Chaetoceros spp and Proboscia alata, had moderate to high abundance. All of these species is commonly found during the autumn period in the Barents Sea. In September 2008 the diatom Corethron hystrix was observed at the mid section of the transect Bear Island-Fugløya. This species has been observed occasionally in the Barents Sea before, but is regarded as more common in the Norwegian Sea, however, this year the species was in percentages the dominating species in the net samples.

Simulations of the primary production in the Barents Sea using the ROMS numerical model showed that there has been considerable interannual variation in timing of the spring bloom at the Fugløya-Bear Island section during the years 1982 to 2007 (Figure 4.3.2). Even though we suspect the model to produce the bloom somewhat too early in the year, we expect the trends to be more correct. The model results showed that the peak of the spring production (bloom) may vary with about one month from year to year and in 2007 the results indicates that the peak was the earliest for the modelled period. Also it seems to be a long term trend towards earlier spring blooming. Figure 4.3.3 shows the timing of the bloom throughout the Barents Sea in 2007. It shows that the bloom was earliest at the western part of the polar front and in the southeastern part of the Barents Sea. Also close to some of the bank areas the bloom started early. Some of these banks are very shallow and water masses may be trapped there. The bank may therefore act as a barrier to downward transport of plankton cells in the same way as a stratification of the water masses. This may explain the early bloom in the bank areas. Simulations by the SINMOD numerical model support high inter-annual variability in primary production related to inflow of Atlantic water and ice-distribution, but no long-term trend was observed in total annual primary production for the years 1995-2007. There seems to be a change in timing occurring before any eventual increases in total annual primary production is seen.

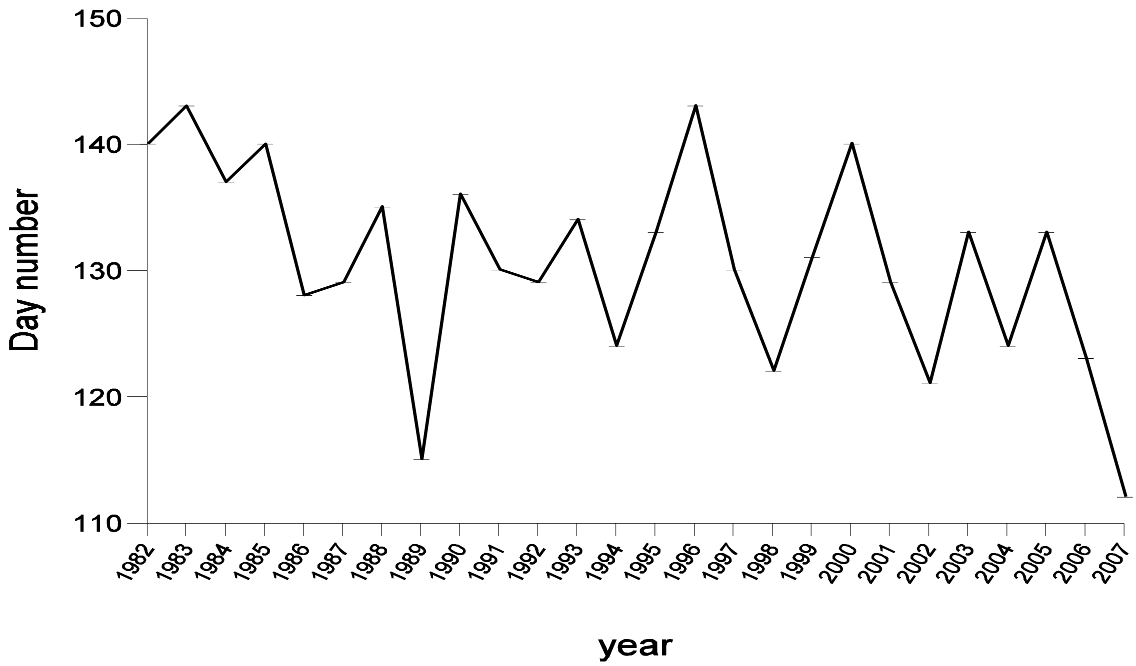

Figure 4.3.2. Modelled day number of peak diatom spring bloom at the Fugløya-Bear Island section during the period 1982 to 2007 using the ROMS numerical model

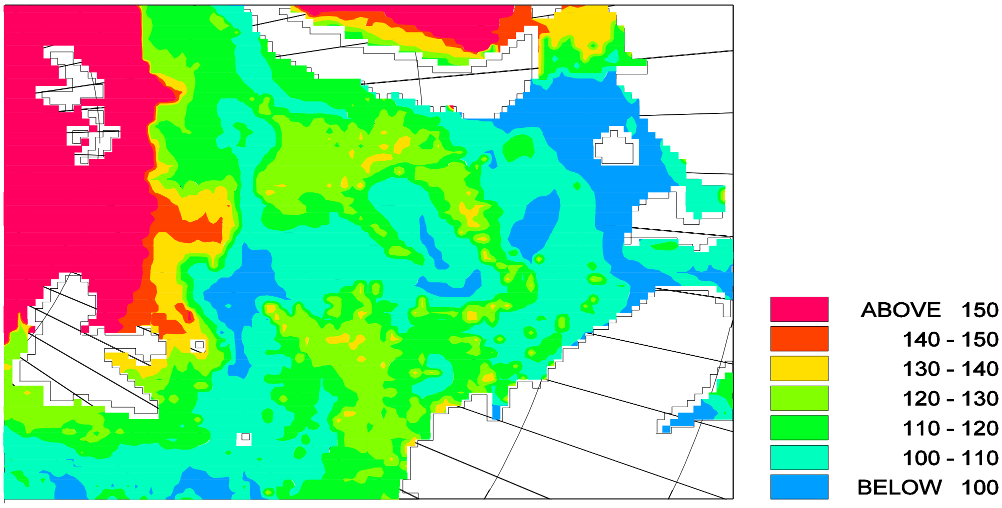

Figure 4.3.3. Modelled day number of peak diatom spring bloom in 2007 using the ROMS numerical model

4.3.2 Zooplankton

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This chapter focuses on the current and expected state of the zooplankton communities in the Barents Sea. In particular, it is given an overview of the communities of meso-, macro- and gelatinous zooplankton in the open sea and in the coastal waters of Kola Peninsula. Furthermore, it is described how the copepod communities react on change in the hydrographical condition in the Barents Sea.

4.3.2.1 Meso-zooplankton

The horizontal distribution of mesozooplankton in 2008 is shown at the Figure 4.3.4. According to the joint ecosystem survey, the average zooplankton biomass was clearly below the long-term mean, and the spatial coverage revealed very low zooplankton biomass in the central parts of the Barents Sea – but with some scattered higher values recorded in the central part of the Barents Sea and along the border of the Russian zone. In the western part of the Barents Sea, a well defined area of higher zooplankton abundance was observed south of Bear Island, but its areal extension was much less pronounced compared to previous years. It has to be noticed that both Norwegian and Russian sampling coverage is poor north of 78°N, except for the area between Novaya Zemlya and Franz Josef Land. Compared to the situation in 2007, it seems that areas of high mesozooplankton biomass are extended eastward into the Russian zone in 2008.

The average zooplankton biomass in the western and central Barents Sea in 2008 was 6.48 g dry weight m-2 compared to 7.13 g in 2007 and 8.63 g in 2006. These values are based on WP2 hauls (Norwegian data) covering the whole water column and depths less than 500 m (Figure 4.3.7). However, the average value for 2008 was based on only 98 stations which are considerably lower than the 145 stations covered in 2007. Combining both Russian (Juday) and Norwegian data (WP2), the average zooplankton biomass for a total of 171 stations was 7.15 and 7.7 g m-2 dry weight in 2008 and in 2007 respectively. These values are less than what was observed in 2006 (8.4 g m-2). However, in the Russian sector alone, the average biomass in 2008 was estimated to 8.05 g m-2dry weight (N=81 stations from bottom-0m).

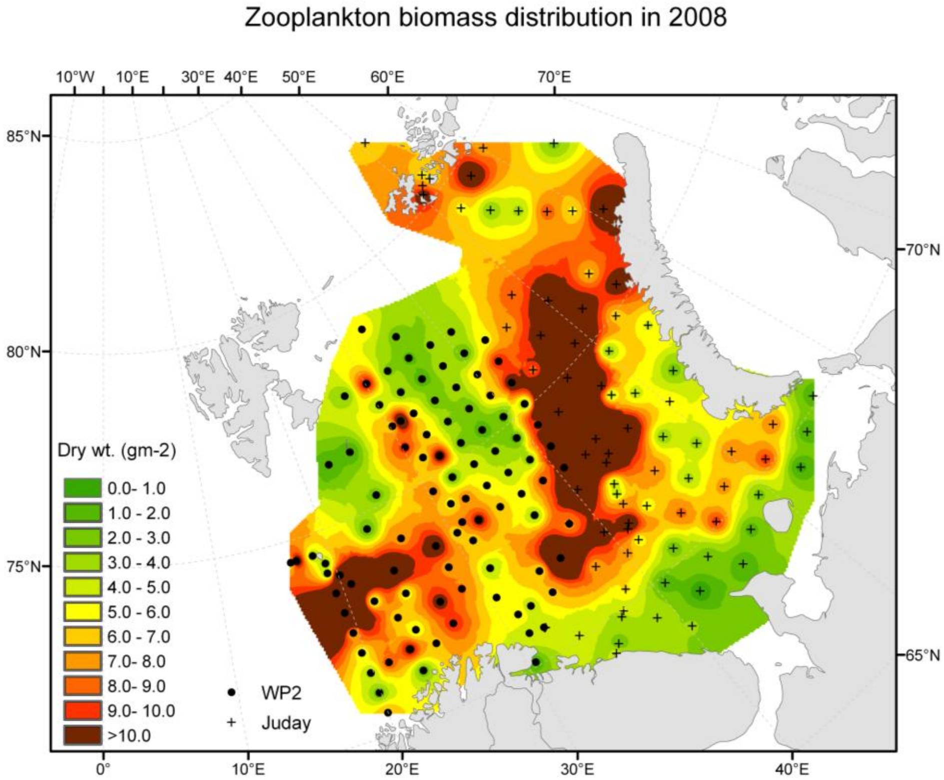

Figure 4.3.4. Distribution of zooplankton dry weight (g m-2) from bottom-0 m in 2008. Data based on Norwegian WP2 and Russian Juday net samples (IMR/PINRO/MMBI).

The examination of the zooplankton composition showed a predominance of the three species Calanus finmarchicus, Calanus glacialis and Calanus hyperboreus), but euphausiids, chaetognaths, and in some cases pteropods, had high biomass estimates. C. finmarchicus was the main species in terms of biomass in the western parts of the Barents Sea, whereas C. glacialis dominated in the northeastern parts. At the same time there were local differences in biomass distribution.

The importance of water mass characteristics on zooplankton abundance for western and central parts of the Barents Sea is shown in Table 4.3.1. It is again apparent that the average zooplankton abundance was highest in the Atlantic water masses (8.5 g dry-weight m-2), and in mixed water of Atlantic and coastal origin (6.0 g dry weight m-2). Quite low biomass was found in pure coastal water masses in 2008 (3.9 g dry weight m-2). This was significant lower compared to 2007 (6.6 g dry weight m-2), but not as low as what was observed in 2006 (1.6 g dry-weight m-2). This year to year biomass variability in coastal waters can be understood from the high horizontal heterogeneity of the zooplankton biomass (Figure 4.3.4), and the relatively low number of sampling stations.

The observations showed that the eastern part of the Frantz Josef Land had more advanced development of C. finmarchicus in 2008 compared to 2007. It was concurrently observed a significant increase in the population of juvenile C. glacialis, and the reproduction in the first half of September 2008 occurred farther north in 2008 (79-82°N) than in 2007 (79°N).

Table 4.3.1. Zooplankton average dry weight (g m-2) in different water mass categories in 2008. Based only on Norwegian hydrographic data and biomass data from WP2 net samples.

	No stations	Average dry weight (gm^{-2})	Standard deviation
North Atlantic water	41	8.5	7.0
Coastal water	3	3.9	2.6
Coastal/North Atlantic water	8	6.0	2.3
Arctic water	6	4.5	3.5
Polar front water	39	5.1	4.8

The biomasses in 2008 in the bottom-0 m layer differed from 2007 in the smaller amplitude equivalent to 5.5-13.7 g m-2 versus 3.2-24.9 g m-2 in 2007. This was caused by the high abundance of juveniles in 2008. In the eastern parts of the Barents Sea (Admiralteistvo Peninsula, Jelaniya Cape) the situation was similar to what was observed off the Novaya Zemlya Shallows – except for the high proportion of Calanoida eggs and nauplii as well as juvenile C. glacialis. The total biomasses were here not higher than 3-8.5 g m-2, except for the southern areas of Jelaniya Cape where the biomass reached 13.4 g m-2 due to high abundance of C. finmarchicus of older stages.

The general distribution pattern of copepod species south of Franz Josef Land in 2007 is shown in Figure 4.3.5. High concentration of the Arctic species C. glacialis, M. longa and P. minutus were observed in the whole studied area. In September, individuals of all life stages (nauplii, younger copepodites to adults) were found in the populations of C. finmarchicus, C. glacialis, and M. longa. This may indicate a prolongation of their breeding period, which is also observed in other Arctic species (Pertsova, Kosobokova, 1996; Orlova et al., 2008, Melle, Skjoldal 1998). Furthermore, it was conspicuous to find higher concentration of C. finmarchicus in eastern and central parts of the Barents Sea in 2008 compared to 2007. The exception was for Franz Josef Land where C. glacialis was more prevalent. Due to the high abundance of juvenile C. glacialis, the total number of small crustaceans reached 150 000-320 000 individuals per m^2 in samples in 2008. This was significantly higher numbers than in 2007 (c.f. Figure 4.3.4 and 4.3.6).

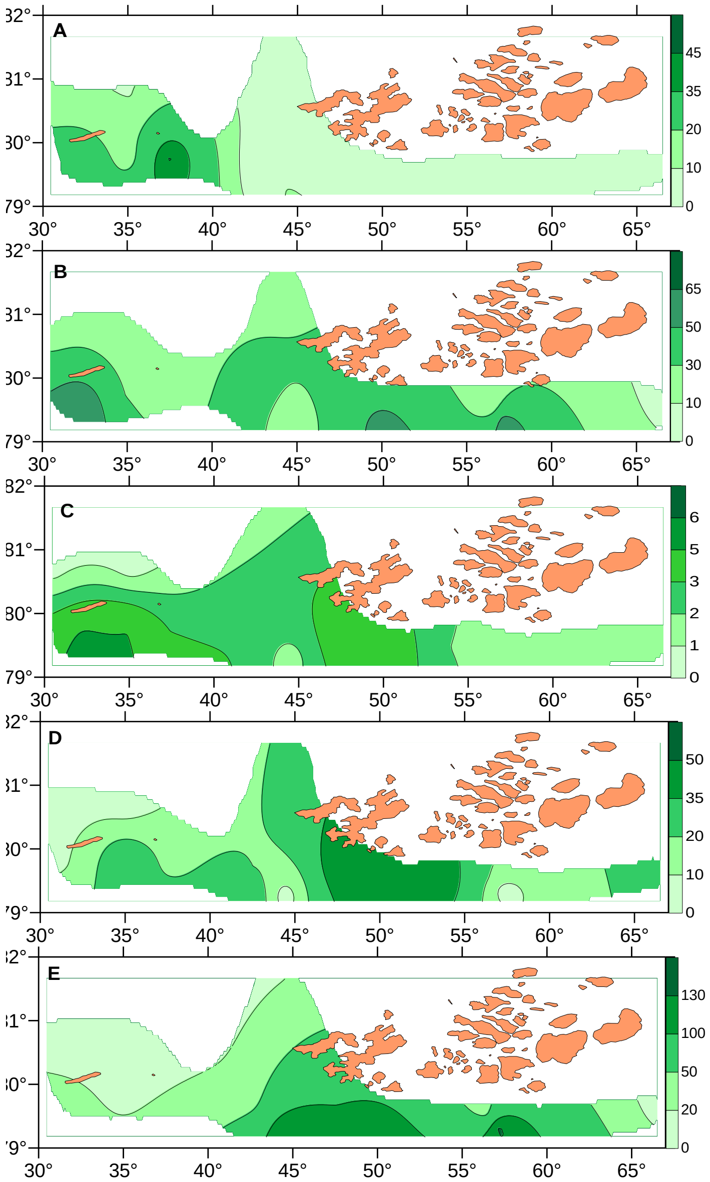

Figure 4.3.5. Abundance of C. finmarchicus (A), C. glacialis (B), C. hyper-boreus (C), M. longa (D) and P. minutus (E) in the Franz Josef Land area in August-September 2007, ths. ind./m2 (based only Russian data from Juday net samples).

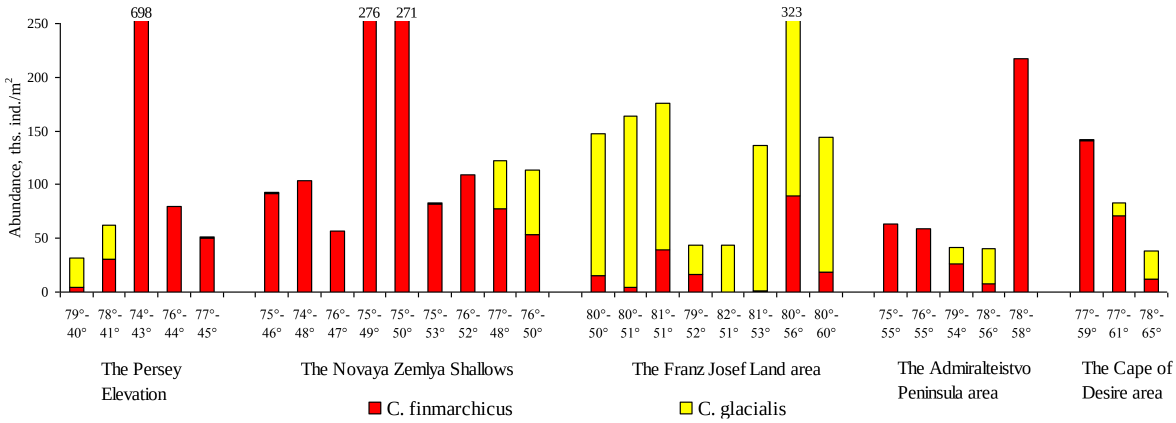

Figure 4.3.6. Abundance of C. finmarchicus and C. glacialis in August-September 2008 (based only Russian data from Juday net samples).

The study of age structure of the most abundant species showed that the population of C. finmarchicus north of 78°N consisted of copepodites CIV (more seldom - CV), and the proportion of juveniles CI-III increased to the south. In the eastern parts of the study area, C. finmarchicus was mainly found as CIV-V. Among the adults, mainly females occurred. In the western areas of FJL and the Persey Elevation, where the species abundance was maximal high, the population of C. glacialis was mainly represented by juveniles belonging to the stages CI-III, and the portion of juveniles increased eastward. In most of the areas, overwintered crustaceans in stadium CIV (more seldom CV) were present. Mature individuals – primarily females – occurred in great numbers right south of FJL. Intensive reproduction of C. glacialis and C. hyperboreus was found in broad areas between 32-66°E.

C. glacialis in stages CIII-VI was found to constitute roughly 50-60% of the total biomass in the north and northeastern parts of the study area. C. hyperboreus, M. longa, as well as the representatives of Pteropoda (Clione limacina) and Sagitta were common, whereas C. finmarchicus was less important. The total biomass varied between 1.2-11 g m-2, and the portion of Euphausiidae and jellyfish were quite high in some parts (0.5-8.8 g m-2).

The state of zooplankton in the Barents Sea in 2007-2008 was highly affected by two important factors: a) the weakening of the total discharges of Atlantic water into the North Cape Current, into the northern branch of the North Cape Current and into the Bear Island Current, and b) the very dynamical state of seaice during the summer period. The first factor caused a reduced transportation of C. finmarchicus from the Norwegian Sea to the Barents Sea. The second factor caused a predominance of C. glacialis and P. minutes (Orlova et al., 2008). However, it is expected that C. finmarchicus gradually will accumulate and become more abundant in the Barents Sea as the ice is retreating.

4.3.2.2 Macroplankton

During the PINRO atumn bottom trawl survey in 2007-2008, samples were collected as a basis for estimation of pre-spawning stock of euphausiids (Figure 4.3.7 A, B). The study showed that the abundance of euphausiids crustaceans was higher than the long-term means from the sampling area, and the arctoboreal species Thysanoessa inermis was the most dominating species.

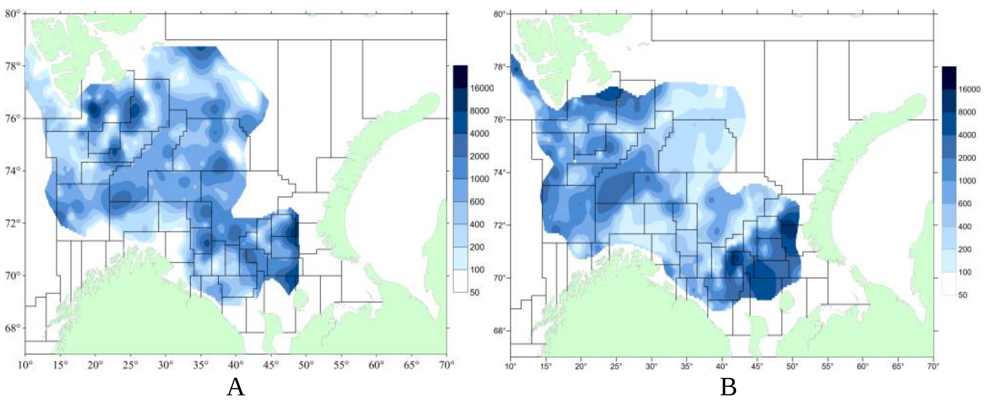

Figure. 4.3.7. Distribution of euphausiids in the near-bottom layer in autumn 2007 (A) and 2008 (B), ind./1000 m^3.

The average abundance of these small crustaceans was higher in 2008 compared to 2007 (Figure 4.3.8), and the density of euphausiids aggregations was noticeably lower in the central and western parts of the Barents Sea. On the contrary, the abundance of euphausiids exceeded long-term means by 3 times in the south and southeastern parts with a number of 1200 individuals per 1000 m3. The abundance of the warm-water species Meganyctiphanes norvegica has stayed relatively high in the central Barents Sea with a number of up to 110 individuals per 1000 m3, and 170 individuals per 1000 m3 in coastal areas. The abundance of this species has in the meanwhile decreased in the western and eastern areas (Figure 4.3.9).

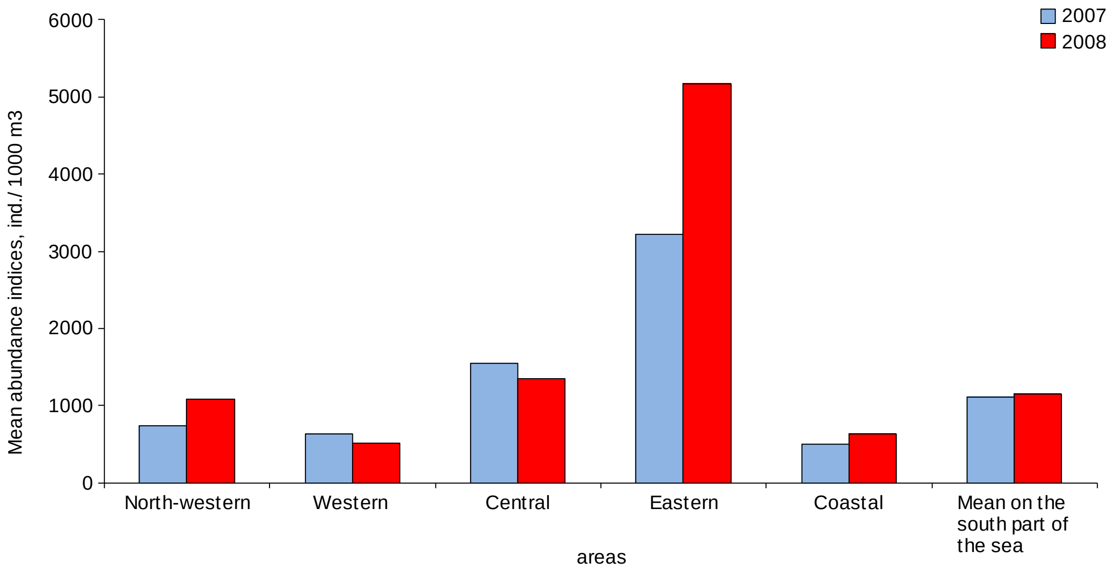

Figure 4.3.8. Mean abundance indices of euphausiids in the North-Western, Western, Central, Eastern and Coastal areas of the Barents Sea in autumn 2007 and 2008 (based only Russian data from trawl net samples).

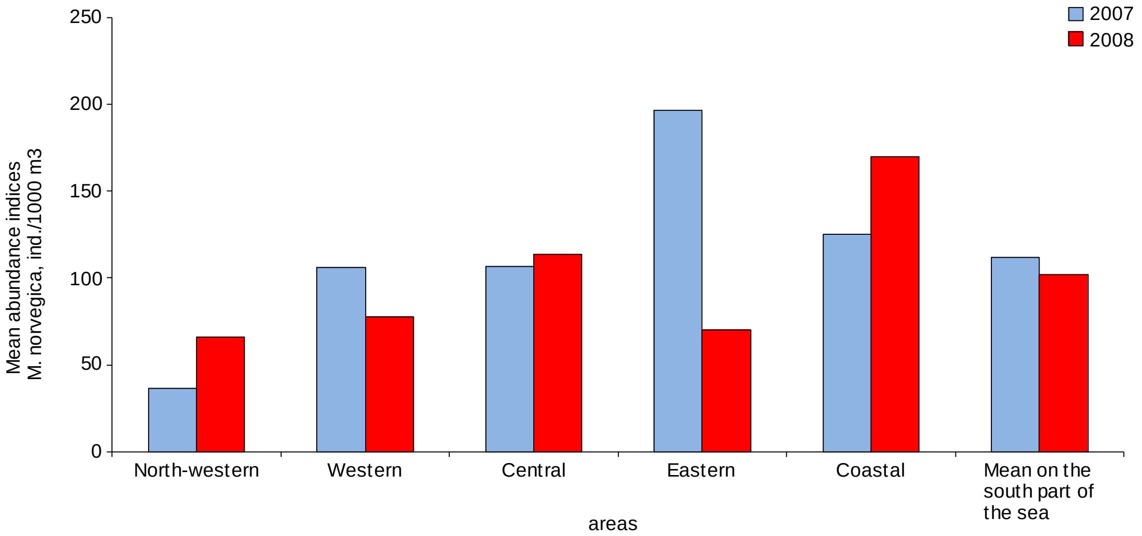

Figure 4.3.9. Mean abundance indices of Meganyctiphanes norvegica in the North-Western, Western, Central, Eastern and Coastal areas of the Barents Sea in autumn 2007 and 20082008 (based only Russian data from trawl net samples).

It’s assumed that the decrease of meso- and macroplankton aggregations in the center and western parts of the Barents Sea is probably caused by higher fish predation – in particular from increasing stock of capelin.

4.3.2.3 Gelatinous zooplankton

Figure 4.3.10 gives the distribution of gelatinous zooplankton caught by pelagic trawling in 2007 and 2008.

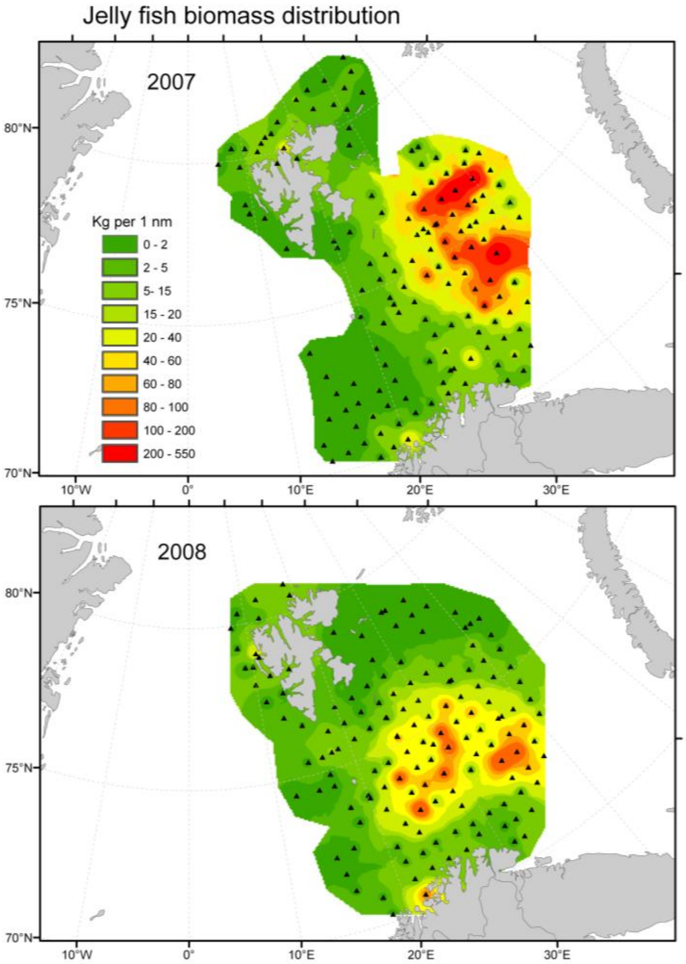

Figure 4.3.10. Distribution of gelatinous zooplankton based on catches from the pelagic Harstad trawl in 2007 and 2008. Numbers are standardized to kg·trawldistance-1.

The results showed a higher abundance of gelatinous zooplankton species in 2007 compared to 2008. This was particularly evident between longitudes 30-40ºE and 75ºN. In 2008, the highest abundance of gelatinous zooplankton was found more south and west in the Barents Sea than the previous year. Both in 2007 and in 2008, the distribution of “jellyfish” showed a considerable overlap with regions poor in mesozooplankton biomass. The data should however be interpreted with some caution since many smaller “jellyfish” species are not sampled adequately with the method used.

The majority of hauls were conducted as standardized stepwise hauls in the 40-20-0 m depth interval, but a few hauls were operated deeper. The catches were adjusted for time of trawling. It is assumed that the results mainly reflect the occurrence of the larger Scyphozoan medusa of the genus Aurelia and Cyanea. Hence, the occurrence of smaller Ctenophora species cannot be verified the way the data has been extracted and compiled except for some larger and more robust forms. (This species and some small “jellyfish” are nevertheless trapped in WP2 net, and this method should be used in the future.)

4.3.2.4 Zooplankton community in the Kola Peninsula offshore zone in 2007-2008

According to the zooplankton observation in 2007-2008 at the different parts of the Kola Peninsula coastal areas, there are between 19-30 species and higher taxonomic groups of zooplankton. The abundance varied from 2500 – 38 500 individuals per m3 with a pronounced decrease in abundance eastward. Copepods were the dominating species in the samples with up to 90 % of total number of individuals. Boreal species as C. finmarchicus, T. longicornis, A. longiremis and C. hamatus were particular dominant compared to the cold waters species C. hyperboreus, M. longa, P. minutus and Microcalanus sp.

Data sampled from Dolgaya between May and September 2008 allows us to characterize the seasonal changes in composition, and quantitative parameters of the dominant groups. In May, copepod nauplii and younger copepodite stages of C. finmarchicus (I – III) was dominant and was found to comprise 90 % of the biomass. C. finmarchicus also dominated in June, but the species was found mainly as stage four. By July, neritic species of the copepods such as A. longiremis, C. hamatus, T. longicornis and the cladocerans E. nordmanni, P. leucartii became most abundant. Their total number reached up to 1600 individuals per m3 – composing 36 % of the community abundance. Predominant species were O. similis (21 %) and meroplanktonic forms (17 %). In August zooplankton community was represented mostly by benthic larvae of Cirripedians and Bivalves. They contributed for more than 80 % of total abundance. During September, the numbers of the meroplanktonic complex were reduced and copepods took back their otherwise dominant positions.

To summarize, during the period from May to September the species community was successive replaced by the three dominant components: C. finmarchicus; neritic copepods; and meroplanktonic forms.

Comparing abundance and life stages of Calanus species between years with different seawater temperature regimes.

4.3.2.5 Fugløya-Bear Island (FB) transect

The stations in the Fugløya-Bear Island (FB) transect are taken at fixed positions located at the western entrance to the Barents Sea. The numbers of sampled stations are normally 5 to 8 depending on the weather conditions. In this study, four stations, representing different water masses (coastal; Atlantic; and mixed Atlantic/Arctic water) in 1996 and 2007, were analyzed for species composition of the two abundant species C. finmarchicus, and C. glacialis, and the occurrence of C. helgolandicus in the March and August. C. helgolandicus is quite similar in appearance to especially C. finmarchicus, but is a more southerly species with a different spawning period. This species has in recent years become more frequent in the North Sea and southern parts of the Norwegian Sea (Svinøy transect), and it’s expected that C. helgolandicus will be found in grater abundance in the Barents Sea in the years to come.

C. finmarchicus was the most dominant species in august 1996 with abundances close to 180 000 individuals per m-2 (Figure 4.3.11). Although one would expect that the number of individuals per m-2 should increase in 2007 compared to 1996 due to warming, this was not true. The development of C. finmarchicus in the western part of the Barents Sea starts in March-April close to the coast, and progresses in time northwards along the section (Figure 4.3.11). The average abundances of the cold-water species C. glacialis was, as expected, somewhat higher in the cold year 1996 (4200 individuals per m-2) compared to the warmer 2007 (2700 individuals per m-2). The species was found in rather low abundances in both coastal and Atlantic waters (70º30’ and 72 ºN) at all time periods. Highest abundances occurred close to Bear Island in mixed Atlantic/Arctic waters.

Samples from 8 stations in March and August from 1996 and 2007 were examined to record the numbers of individuals of C. helgolandicus. Very few individuals of C. helgolandicus were observed both in 1996 and in 2007. This result indicates that the warm water species is slowly spreading into the Barents Sea.

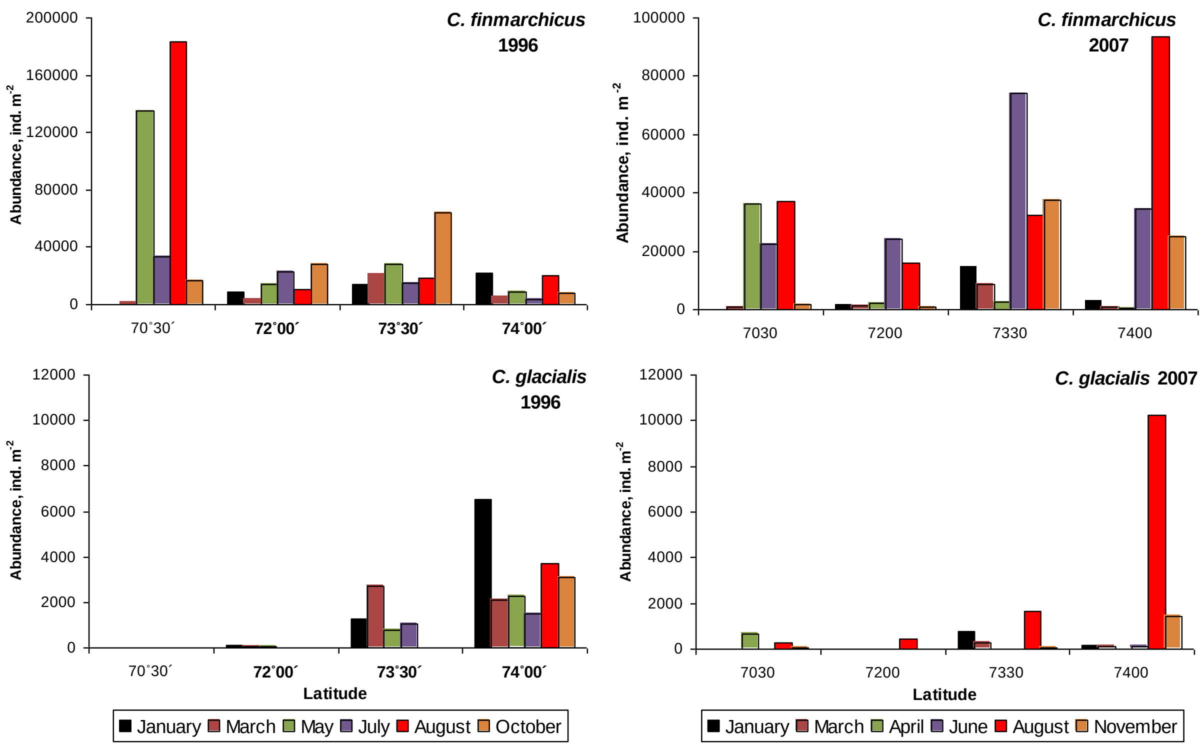

Figure 4.3.11. Development of copepod abundance along the transect Fugløya-Bear Island in 1996 and 2007. On a few occasions, when stations were lacking at a particular position, stations closest to that were analyzed.

4.3.2.6 Kola section

C. finmarchicus was a dominant species among copepods on the Kola section, which is located further east of the Fugløya-Bear Island (FB) transect. Comparison of C. finmarchicus abundance and life stage structure are here studied in two relatively warm years (1983, 1992) and in an abnormally warm year (2008, Figure 4.3.12, Russian data). The results for 2008 showed that all C. finmarchicus stages, including nauplii and young copepodites, were more abundant this year along the whole section than in 1992 and in particular for 1983 (Figure 4.3.12). A quite new feature in 2008 was that young specimens of C. finmarchicus in stage CIV and CV were found also in deeper waters. The relatively high abundance of nauplii and young copepodites in 2008, in particular compared to 1983 has obviously provided favourable feeding conditions for relevant fish larvae (Karamushko and Karamushko, 1995).

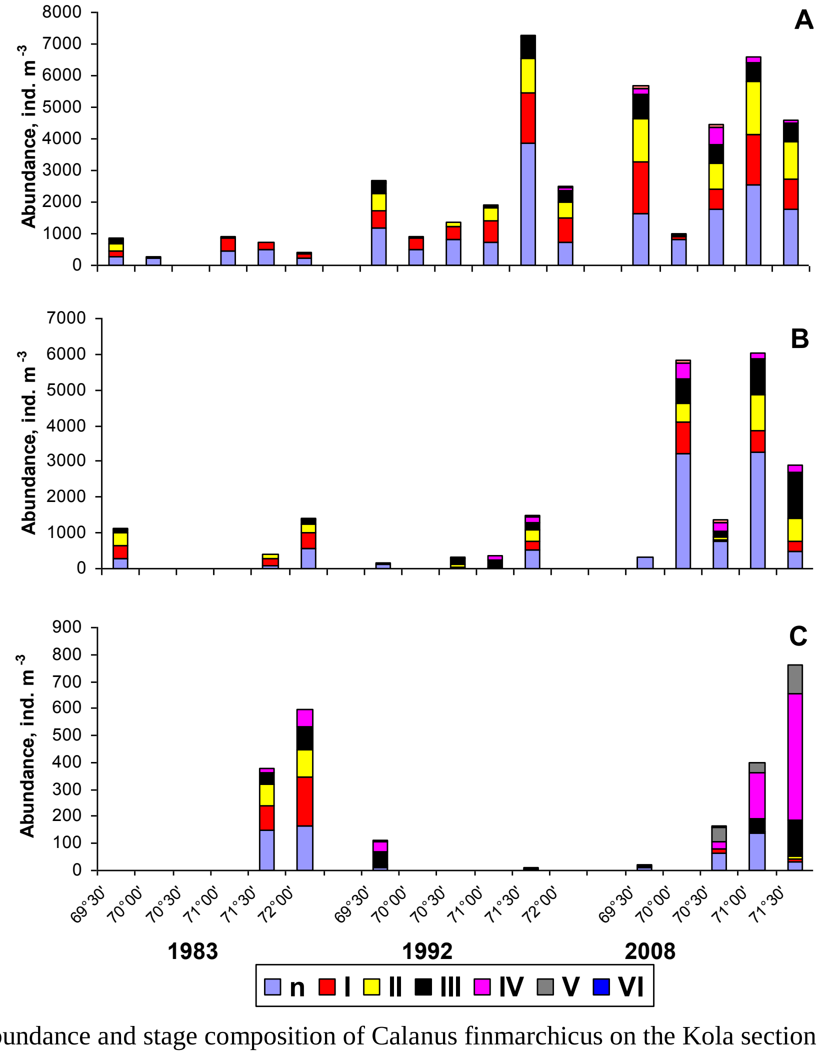

Figure 4.3.12. Abundance and stage composition of Calanus finmarchicus on the Kola section by Juday net catches in May 1983, 1992 and 2008. A – 0-50 m B – 50-100 m, C – 100m-bottom.

4.3.2.7 Expected situation

The average mesozooplankton biomass in August and September 2008 for the Norwegian sector of the Barents Sea was below the long-term mean, and was in fact the lowest ever measured since 1997. The highest biomass was found in the Atlantic water masses which designate the importance of zooplankton transport from the Norwegian Sea into central and western parts of the Barents Sea. The continual declining of mesozooplankton biomasses since mid 1990s suggests that the condition for local production could be less favourable also in 2009.

The general warming of the Barents Sea, and the progressively lesser extent of the winter ice, is expected to bring more warm water species further north and east in the Barents Sea. Evidence for such extension of warm water species, are the considerable amounts of euphausiids found in the stomach content of capelin north of Svalbard in 2007. In addition, large numbers of euphausiids were also observed in the stomachs of both capelin and polar cod in the central and eastern Barents Sea, and it was observed higher abundance of euphausiids in the eastern Barents Sea in 2008 compared to 2007 (c.f. Figure 4.3.8 and Figure 2.6.4). The aggregations of juvenile euphausiids north of 78ºN, and the high biomass of krill north-west and the south-east in the Barents Sea, further support the impression that krill is expanding their distributional range in the Barents Sea (Figure 4.3.7). The three species Thysanoessa inermis, Meganyctiphanes norvegica and T. raschii was the most dominating elements. The increasing occurrences of the krill species Nematocelis megalops over the last 10 years is also a good indication of the migration of typical Atlantic krill species into the Barents Sea.

The considerable drop in average mezozooplankton biomass in the Barents Sea lately is probably caused by the significant increase in the biomass of capelin between 2006 and 2008 – from less than 1 to about 4.4 million ton. Other plankton consumers like herring, juvenile cod, haddock and redfish are also considered to have an important influence on the zooplankton biomass – although their abundance were reduced in 2008 compared to 2007 (except for the 0-group of capelin and cod). Also the abundance of blue whiting and sandeel were lower in 2008 compared to previous years, and it is presumed that the predation pressure on the zooplankton communities from many 0-group plankton consumers will be reduce somewhat in the years to come.

Gelatinous zooplankton like medusa and ctenophores are also considered to be important predators on mesozooplankton in the Barents Sea, but their influences are difficult to assess quantitatively. Nevertheless, it was observed that the low zooplankton abundance in the central part of the Barents Sea in 2007 and 2008 coincided with high gelatinous zooplankton abundance. How this affects the abundance of capelin is uncertain. It could be that gelatinous zooplankton prefer a rather different size spectrum of zooplankton and fish larvae than capelin, hence their impact as competitors to capelin are less significant.

Taking into consideration the hydrographic conditions and the long-term dynamics of zooplankton development, the spawning of the main zooplankton species of copepods and euphausiids is expected to start in mid April in the southwestern areas of the Barents Sea. Having overwintered, these groups of crustaceans, along with the warm water species that are transported from the Norwegian Sea, will cause a zone with high density of zooplankton in the northwestern and western part of the Barents Sea. In late May and June, euphausiids will descend to the bottom layers where they will be more available as feed for adult cod.

The relatively low zooplankton biomass in western parts of the Barents Sea was not observed in the Russian sector both in 2007 and 2008. The reason for this is possibly because capelin these years was distributed in western and northern part of the Barents Sea implying a much higher zooplankton survival eastward in the Barents Sea. It's also evident that the high zooplankton biomass in east was protected from predation by polar cod which has its main distribution further north. The high zooplankton survival rate in the eastern part of the Barents will probably bring out a high overwintering stock that could support a high local production in 2009.

4.3.3 Benthos

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4.3.3.1 JAES long term monitoring program

To track environmental impacts on benthic assemblages, large scale, long-term monitoring of the Barents Sea bentos has been underway since 2005. The "Russian-Norwegian Joint Annual Ecosystem Surveys" (JAES) project addresses the need by providing both spatial and temporal data of benthic fauna from more than 400 stations annually since 2006.

A total of 315 invertebrate taxa caught as 'by-catch' was recorded through 2007. By-catch investigations indicate that the current distribution of mega-benthos in the Barents Sea is variable from area to area but might also vary from year to year. The biomass-hotspots, recorded every year from 2005 to 2008, are located at "shallow water areas" as the Tromsø Flake, on the Spitsbergen Bank (large variety of conspicuous epifauna species), the Olga Strait (large aggregations of brittle stars also found in haddock stomachs), Goose Bank and Novaya Zemlya Bank. The high biomass of the bank slopes consists mostly of epifauna feeding on the rich amount of detritus washed out from the central parts of the bank. A generally reduced biomass towards the west is likely correlated with reduced food inputs (Zenkevitch 1963).

Six long-term monitoring areas have been established to design a method to follow fluctuations in biomass in the Barents Sea (Figure 4.3.13 a and b). The areas were selected using criteria such as: anthropogenic impacts; natural variation; feeding area of bottom fish, invasion of new species and geographic variation. Results (Figure 4.3.13b) indicate a drop in biomass between 2005 and 2007 at the Western Slope (Area 1, reduced catch of sponges) and Hopen Deep (Area 6; reduced catch of several species of sea stars). Simultaneously there was a increase in benthic-biomass on North Cape Bank (Area 2) and Murmansk Coast (Area 3) which was related to an increased population of red king crab (Paralithodes camtschtica) while at the Goose Bank (Area 4) an increasing population of snow crabs (Chionoecetes opilio). In 2008, area 1, 2 and 3 drops, while 4 and 5 and 6 were all steady. The drop was partly done to reduced sponge catch, but also (area 2) low coverage of sponge stations and therefore inappropriate data collection. The drop in area 3 was due to a collapse in the red king crab population (se chapter 4.3.4.4 in this report).

It will be of interest to investigate the interaction between the increased snow crab and decreased king crab populations to the preferred prey species selected by these two crabs. It would also be of interest to study the interaction between king and snow crab and fish species that feed on the sea bottom, such as haddock (see 4.3.5.2), long rough dab and skate.

(a) (b)

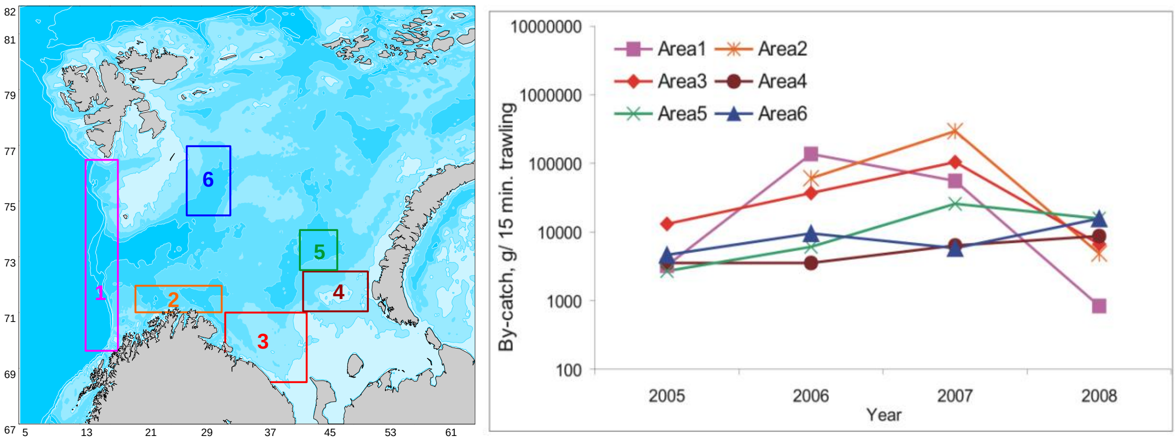

Figure 4.3.13. (a) Established long-term, monitoring areas. Area 1: Western Slope. Area 2: North Cape Bank. Area 3: Kola Coast. Area 4: Goose Bank. Area 5: Shtokman Field. Area 6: Hopen Deep. (Source: PINRO). (b) Epifauna biomass 2005-2008 as mean value of all stations within each monitoring area. Area 1: Western Slope, Area 2: North Cape Bank, Area 3: Murmansk Coast, Area 4: Goose Bank, Area 5: Shtokman Field, Area 6: Hopen Deep. (Source: PINRO).

4.3.3.2 The Shtokman Gas exploration field and Kola section -long term monitoring program

The Shtokman license area (Figure 4.3.14a) has been monitored by MMBI from 2002-2007. The location is deeper that 300m in the eastern Barents Sea. The relief of the sea bottom is monotonous, together with monotonous sediment and benthic communities (Denisenko, 1996, Pavlidis, 1995, Frolova et al, 2004). At present, pollution of the near bottom waters and sediments of this area is insignificant (Ivanov, 2003). Furthermore strong disturbance of sea floor by fish trawling was not recorded in this area (Aibulatov et al 2005).

The Kola section (Figure 4.3.14a and b) are located in the western part of the Barents Sea on 33˚30′ E. It intersects waters of the Murman coastal current (69˚30′-70˚30′ N), and the Murman (70˚30′-72˚30′ N) and Central (73˚00′-74˚00′ N) branches of the North Cape Current (Tereshchenko, 1997). Many stations on this section are deeper than 200 m.

The first benthic investigations at the Kola section were made as early as in the 1930s (Derjugin 1933) which make this study a base line for long-term zoobenthos monitoring (Nesis 1960, Denisenko 1997, 2005).

The fluctuation in the benthic community (taken by grab) over time at the two monitoring areas have shown small fluctuations on the Kola section while comparatively larger fluctuations on the Shtokman area (Figure 4.3.14b). The two monitoring areas have the same type of biocenosis dominated by the polychaeta Spiochaetopterus typicus. The mean biomass on the Kola section is two times lower than the mean biomass on the Shtokman area. This fact might be explained by the difference in temperature but also by the fact that the Kola section are more strongly influence from the bottom trawling fishery than the Shtokman area.

The mean biomass value over time at the Shtokman area is slightly negative. But in generally the current situation on both monitoring areas might be described as a moderate stable state.

(a) (b)

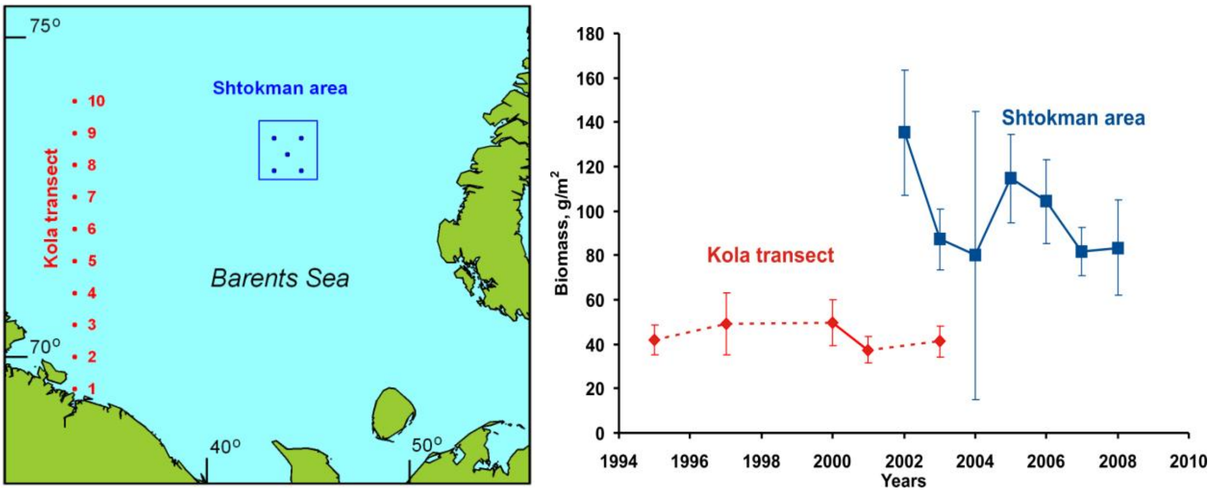

Figure 4.3.14.. (a)The Kola section (33˚30′ E) and Shtokman license area in the eastern Barents Sea. (source: MMBI and PINRO). (b). Bottom community variation along the Kola Section (red) and Shtokman area (blue) investigated by van-Veen grab (source: MMBI and PINRO)

4.3.4 Shellfish

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4.3.4.1 Pandalus borealis

The 2008 stock assessment (ICES) indicated that the stock has been exploited in a sustainable manner and has remained well above the precautionary reference limit throughout the history of the fishery. The advised TAC (quota) for 2009 is 50 000 tonnes.

Mortality: The fishing mortality has been below the upper limit reference (Flim) throughout the exploitation history of the stock. The risk that F exceeded Flim is estimated at about 1% for 2008.

Biomass: Indices of stock size have increased from 2004 to 2006, but decreased again from 2006 to 2008. The estimated risk of stock biomass being below Bmsy at end 2008 was 4%, but less than 1% of being below Blim.

State of the Stock: The stock biomass estimates has varied above its MSY level throughout the history of the fishery. Biomass at the end of 2008 is estimated to be well above Bmsy and fishing mortality well below Fmsy. However, estimated numbers of small shrimp decreased since 2004 which may result in reduced recruitment to the fishery i 2009.

Future prospects: Given the high probability of the stock being considerably above Bmsy, risk of stock biomass falling below this optimum level in the near future is low.

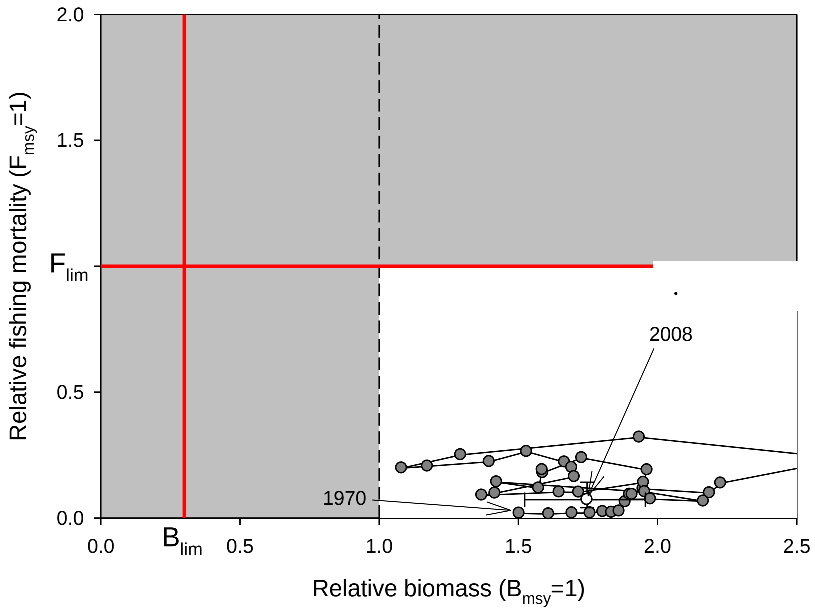

Figure 4.3.15. Estimated annual median biomass-ratio (B/Bmsy) and fishing mortality-ratio (F/Fmsy) 1970-2008. The reference points for stock biomass, Blim, and fishing mortality, Flim, are indicated by the red (bold) lines. Error bars on the 2008 value are inter-quartile range

4.3.4.2 Chlamys islandica

Russian studies on the Iceland scallop were conducted off Svatoy Nos Cape in the Barents Sea in 2008. The commercial stock was estimated at 137,000 tonne. Compared to 2007, it decreased by 20%. Individuals with the shell height from 70 to 110 mm, modal length of 90-100 mm and average size of 95,7 mm were predominant in catches.

The commercial stock has been decreasing in this area since 2001 (Figure 4.3.16). The main reasons are impacts by scallop catching and fishing, fungus infection and poor recruitment to the fishable stock. The increase in the number of juveniles has been observed since 2005.

The Iceland scallops stocks in the Svalbard area has not been surveyed since 2006, but the status of these stocks are probably not changed since there have been no fishery in the area. The coastal beds were investigated in 2007 and no major changes were observed compared to 2005. There is probably no fishery going on for the Iceland scallop in coastal beds either.

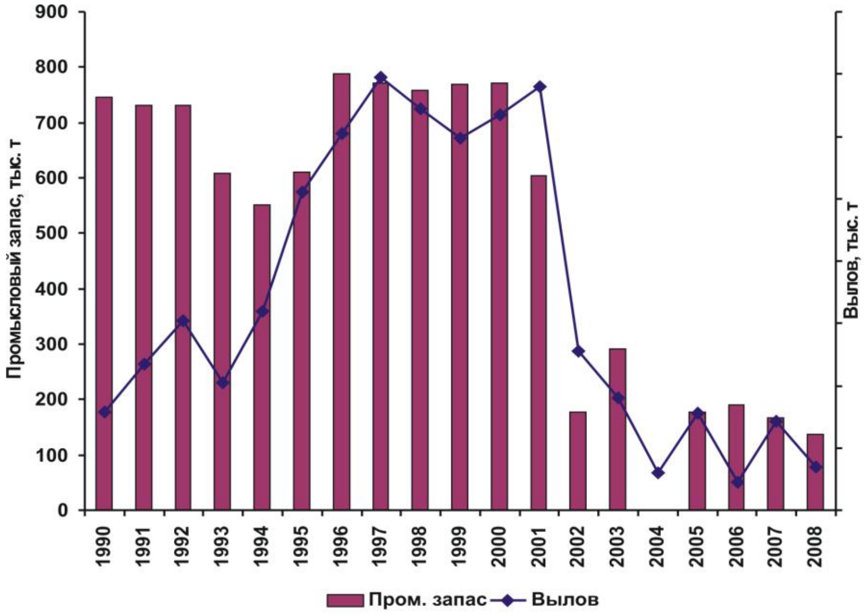

Figure 4.3.16. Commercial stock and catch of Iceland scallop at the site of commercial aggregations off Svatoy Nos Cape in the Barets Sea, 1990-2008.

4.3.4.3 Snow crab (Chionoecetes opilio)

The snow crab is recorded as bycatch in trawl and gillnet fishery in Norwegian waters with an increasing frequency. The main part of the catches is in the northern part of the Barents Sea and in the Svalbard Conservation zone, but several catches has also been taken along the coast of Finnmark. The snow crab is expected to increase in abundance in the Norwegian part of the Barents Sea and in the Svalbard Conservation zone, but will probably appear more northerly distributed than the red king crab.

According to results of the snow crab ecosystem and trawl surveys in 2008 the total stock of Chionoecetes opilio in the eastern part of the Barents Sea was estimated at more than 10 million specimens, In the last few years an increased portion of small crabs was observed in the eastern sea. The opilio polulation in the Barents Sea is now in the state of development and the crab status is not yet been determined. Data on snow crabs testify that this true invasive species has successfully adapted to a new environment.

In accordance with the UN Convention on biological biodiversity the snow crab must be destroyed as an invasive species. However, the distribution of Ch. opilio over vast marine areas, specific features of crab biology, rather high abundance with good prospects for its great increase and difficulty of access to some areas of opilio distribution for trawling and other fishing methods are unlikely to allow this process to happen successfully.

This crab species is an abundant inhabitant in bottom communities on the shelf and continental slope of the northern Atlantic and Pacific and is there of great importance as a harvested species. In these areas the annual harvest of opilio amounted to several tens of thousands of tons. Environmental conditions in the Barents Sea suggest that in the foreseeable future the opilio abundance indices would be compared with those in their native habitats.

4.3.4.4 Red King crab (Paralithodes camtschaticus)

In August-September 2008, the densest concentrations of red king crabs, more than 500 ind/sq.km, were observed in the southeastern part of the habitat (Figure 4.3.17). In the rest of the habitat, the density of distribution was low and, as a rule, did not exceed 50-100 ind/sq.km (rarely 250).

The index of fishable stock beyond the 12 n. mile zone in 2008, compared to 2007, decreased by 1,4 times and numbered 5,3 mil. individuals. At the same time, the index of pre-recruit stock I (males in a 133-149 mm carapace width) increased by 2 times and numbered 1,6 mil. individuals. This raises hopes that there will be a considerable recruitment to the commercial stock in 2009.

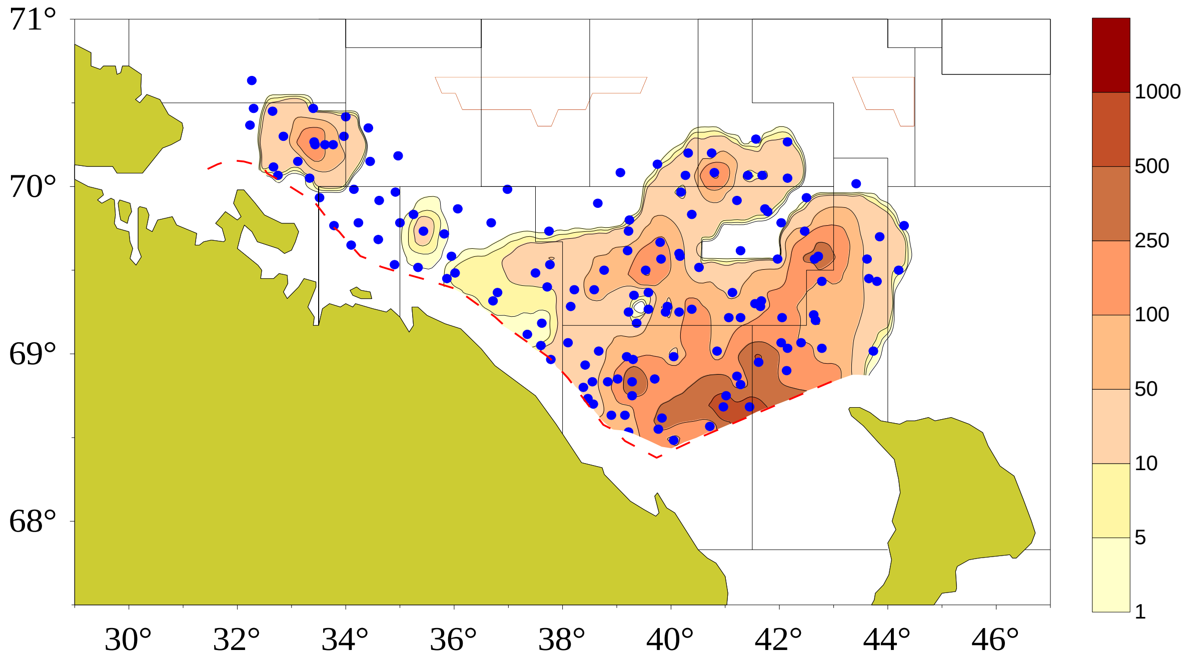

Figure 4.3.17. Quantitative distribution (ind/sq.km) of legal red-king crab males in the Russian waters of the Barents Sea, August-September 2008.

The Russian fishery for red-king crab in 2008 was conducted in accordance with the Regulations for the Northern Fisheries Basin (2007). 31 vessels conducted fishing for red-king crab. The highest fishing efficiency was observed in the eastern part of the habitat, where 61% of the total catch was obtained in the Murman rise are, and 34% of the total catch was taken in the coastal shallow waters.

The official catch of red-king crab in 2008 accounted for 2,500,000 individuals.

Total stock (CL>70 mm) abundance were estimated for all areas of king crab distribution in Norwegian zone, and the estimates were slightly higher in 2006, about 5,2 million specimens. Legal male crab (CL> 137) stock was also estimated to be slightly lower than in 2007; about 0,8 million specimens (Figure 4.3.18). The recruitment to legal male stock has been moderate or low recent years and will probably not change in 2009 or 2010.

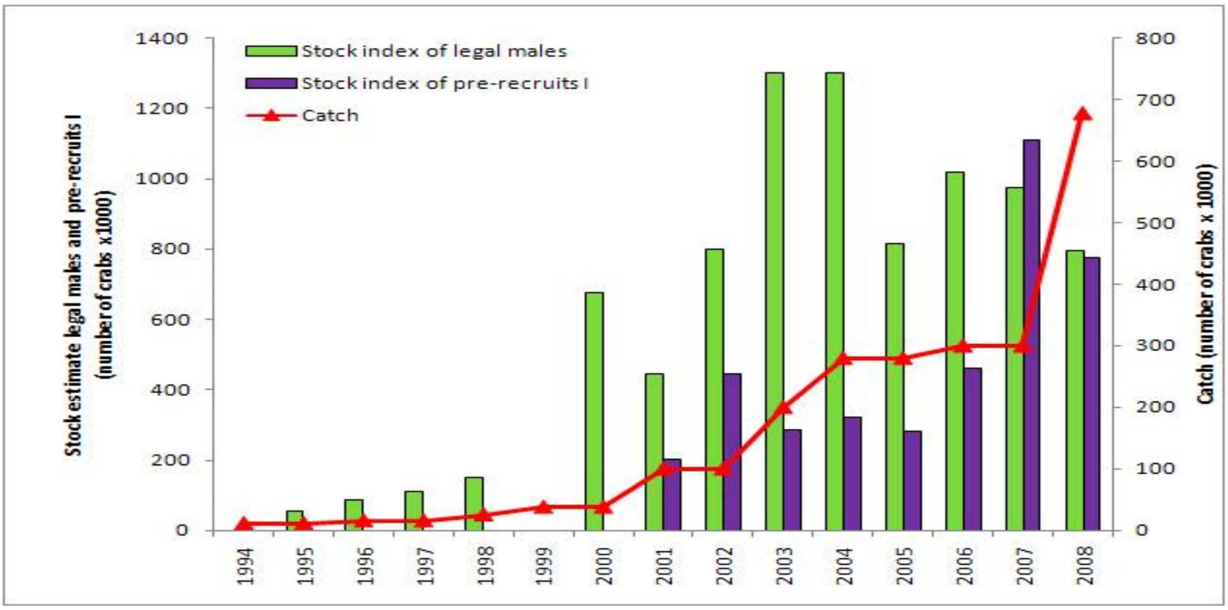

Figure 4.3.18. New legislations for the management of the king crab in Norwegian waters were implemented in 2008 revealing a total quota of 679 thousand male crabs. In addition there was an additional quota of 110 thousand female crabs larger than 137 mm carapace length.

4.3.4.5. Squids and other shellfish species with ecomonical potential

Squids

In Norwegian waters the squid Gonatus fabrichii could form a future fishery due to its abundance. The challenges in such a fishery could, however, be to avoid juveniles of other commercial fish species which often is distributed in the same water masses as the squid. The flying squid Todarodes sagittatus has been more or less absent from Norwegian waters for twenty years, but will most probably form a significant fishery if the stock enhances and the squid return to our waters. By the ecosystem data (RV F.Nansen, Smolensk, Vilnus) G. fabrichii in the last 3 years 2005-2007 was found in the west and north-west parts of this sea. , in central part has low quantities (Golikov at al., 2008). All squids were caught immature (1 - 2 maturity stage). Females dominated (49 from total 82 specimens). The mantle length of males was from 1,5 – to 9,3 sm, and of females from 2,1 – to 8,8 sm. G. fabricii was found on depth from 102 – to 379 m with temperature from 0,50 – to 2,00 C. The total stock of this squid is unknown but as we wrote in the previously chapter might to be several million tonnes.

Other shellfish species

By the expert estimation which base on data of the research investigations in 2008 the total stock of Buccinids in Barents Sea may be 3-18 million tons. Total stock of the clams (Serripes groenlandicus, Ciliatocardium ciliatum and Arctica islandica) may be up to the 4 million tons. Total stock of the large sea-cucumber Cucumaria frondosa – 20,5 thousand tons. The total stock of the sea urchin Strongylocentrotus droebachiensis is about 7,5 thousand tons.

4.3.5 Fish

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4.3.5.1 Cod (*Gadus morhua*)

Based on the most recent estimates of spawning stock biomass (SSB, Figure 4.3.19), ICES classifies the stock as having full reproductive capacity and being harvested sustainably. Based on the most recent estimates of fishing mortality, the stock is at present exploited with a fishing mortality below that intended under the agreed management plan. The SSB has been above Bpa since 2002. Surveys indicate that the 2004-2005 year classes are above average while the 2006-2008 year classes are below average.

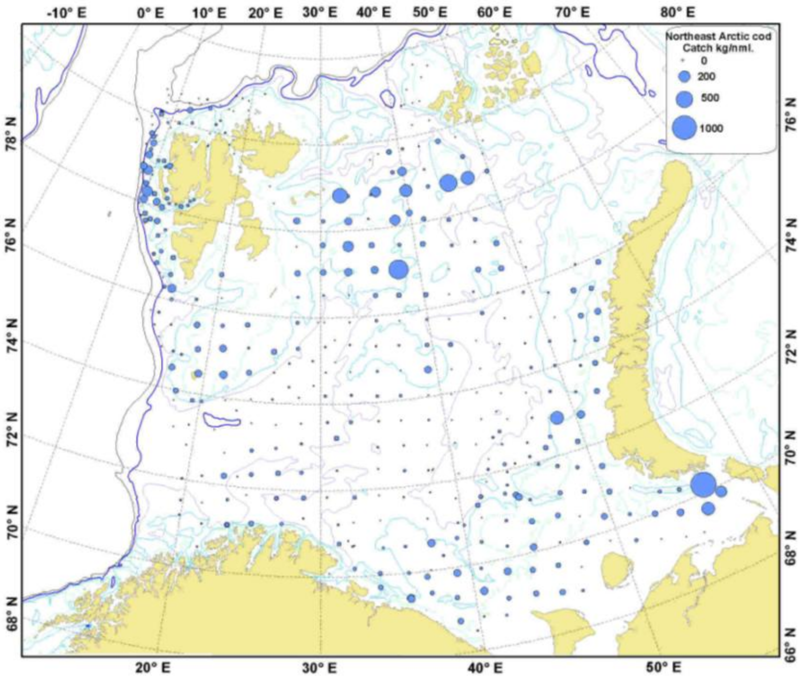

Figure 4.3.19. Distribution of Northeast Arctic cod, August-October 2008.

Fishing mortality was in the range 0.50-0.75 from 2001-2006, but dropped to 0.35 in 2007 and 0.30 in 2008. This fishing mortality is in the range that is associated with high long-term yield and low risk of depleting the production potential. The accepted harvest control rule gives a TAC for 2010 of 577 500 t. This TAC is determined by the 10 % limit on annual increase of the quota, and gives a fishing mortality below that intended under the agreed management plan.

There are concerns about under-reporting of catches in recent years. However, the estimated amount of unreported landings decreased considerably from 2006 to 2008. This is connected with the port state control introduced by NEAFC from 1 May 2007. Unreported landings will reduce the effect of management measures and will undermine the intended objectives of the harvest control rule. It is important that management agencies ensure that all catches are counted against the TAC.

The geographical distribution of this stock is expanding to the north and east. This is related to the increase in temperature observed in the Barents Sea in recent years. It is important that the spatial coverage of the surveys is increased to take this into account.

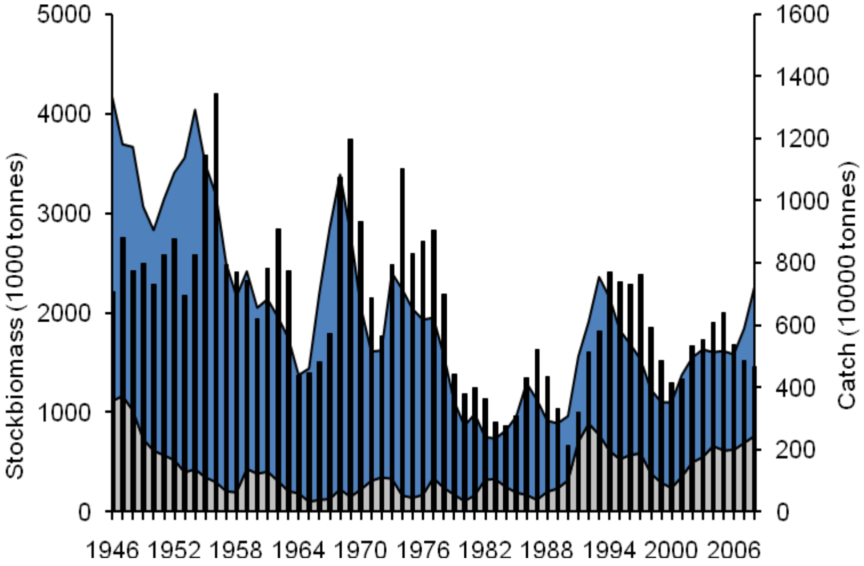

Figure 4.3.20. Northeast Arctic cod, development of spawning stock biomass (grey area), total stock biomass (age 3 and older, blue area) and landings (columns).

4.3.5.2 Haddock (Melanogrammus aeglefinus)

Based on the most recent estimates of SSB (Figure 4.3.21), ICES classifies the stock as having full reproductive capacity and being harvested sustainably. The fishing mortality has fluctuated around Fpa during the last 10 years. The assessment indicates that the spawning stock is at a high level. Very strong year classes of 2004-2006 are recruiting to the fishable stock in 2008-2010, and thus the stock is reaching the highest level observed in the time series, which go back to 1950. The 2007 and particularly 2008 year classes seems to weaker, however. The accepted harvest control rule gives a TAC for 2010 of 242 500 t. This TAC is determined by the 25 % limit on annual increase of the quota, and gives a fishing mortality below that intended under the agreed management plan.

Haddock is taken both as a directed fishery and as bycatch in the NEA cod fishery. Also for haddock there are concerns about under-reporting of catches in recent years. Unreported landings will reduce the effect of management measures and will undermine the intended objectives of the harvest control rule. It is important that management agencies ensure that all catches are counted against the TAC.

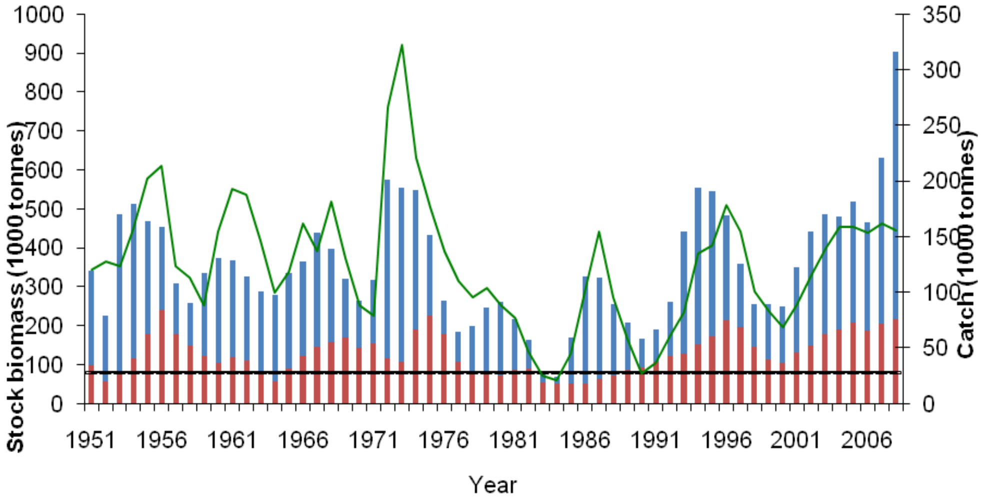

Figure 4.3.21. Northeast Arctic haddock, development of spawning stock biomass (red bars), total stock biomass (age 3 and older, blue bars) and landings (green curve).

4.3.5.3 Redfish (Sebastes mentella and Sebastes marinus)

Deep-Sea Redfish (Sebastes mentella)

Recruitment failure has been observed in surveys (Figure 4.3.22) for more than a decade. However, signs of improved recruitment are now seen in the Barents Sea. In this regard, it is of vital importance that the juvenile age groups be given the strongest protection from being caught as bycatch in any fishery, e.g., the shrimp fisheries in the Barents Sea and Svalbard area. This will ensure that the recruiting year classes can contribute as much as possible to stock rebuilding.

The only year classes that can contribute to the spawning stock in the coming years are those prior to 1991 as the following year classes are extremely poor. Several years' protection and growth of these year-classes could have caused the higher abundance and densities recently encountered along the continental slope and pelagic in the Norwegian Sea. These year classes need to be protected as they offer the only opportunity of increasing the spawning stock for a number of years to come.

A directed pelagic fishery for deep-sea redfish (S. mentella) in international waters of the Norwegian Sea has developed since 2004. This fishery increased to record levels in 2006, and the total catch in 2006 was 33 thousand tonnes, the highest level since 1991. The total catch of S. mentella declined to 20 thousand tonnes in 2007 and 14 thousand tonnes in 2008. It is doubtful whether this catch level is in accordance with the precautionary approach.

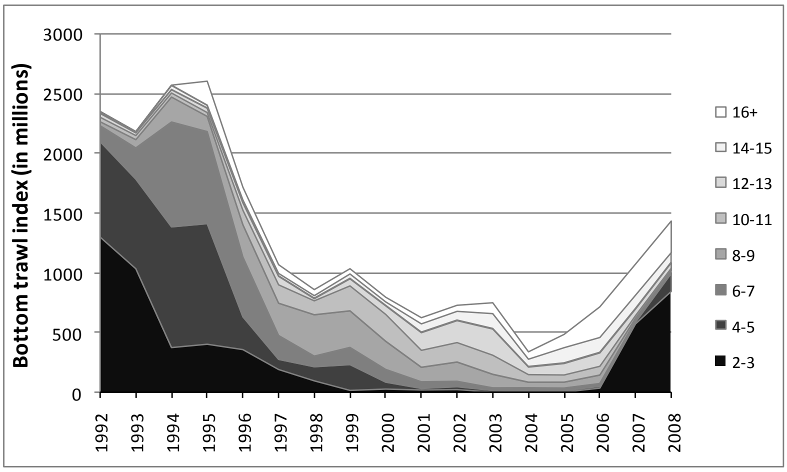

Figure 4.3.22. Sebastes mentella. Abundance indices (by age) when combining the Norwegian bottom trawl surveys 1986-2008 in the Barents Sea (winter) and at Svalbard (summer/fall).

Golden Redfish (Sebastes marinus)

In the absence of defined reference points the state of the stock cannot be fully evaluated. Surveys (Figure 4.3.23) and commercial CPUE show a substantial reduction in abundance and indicate that the stock at present is historically low. The year classes in the last decade have been very low and declining. Presently, this stock is in a very poor condition. Given the low productivity of this species, this situation is expected to remain for a considerable period.

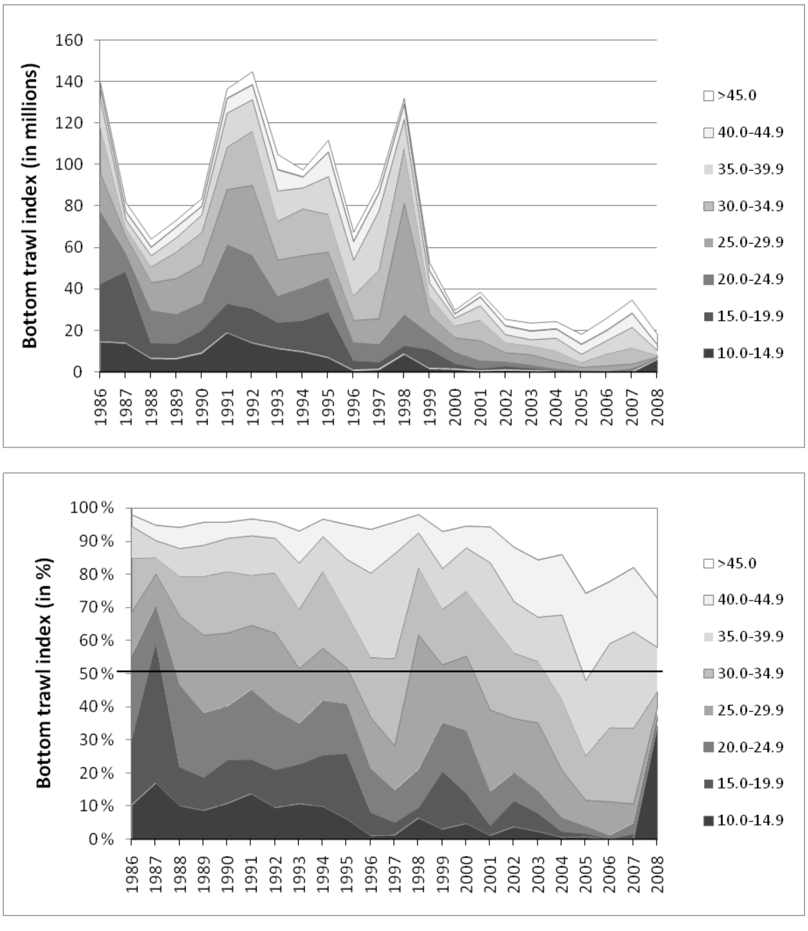

Figure 4.3.23. Sebastes marinus. Abundance indices (by length) when combining the Norwegian bottom trawl surveys 1986-2008 in the Barents Sea (winter) and at Svalbard (summer/fall).Upper panel: Total abundance, lower panel: Length composition.

More stringent protective measures should be implemented, such as no directed fishing and extension of the limited moratorium implemented on this stock, as well as a further improvement of the 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. This will ensure that the recruiting year classes can contribute as much as possible to slowing the decline of the stock. Golden redfish (S. marinus) is currently being caught in a directed fishery and as bycatch in the pelagic trawl fisheries for herring and blue whiting in the Norwegian Sea. Better statistics on this bycatch, and regulations to prevent this continuing, are needed.

The catches have been around 7,000 t for the last 7 years, a level which seems to cause a continued decline of this stock.

4.3.5.4 Greenland halibut (Reinhardtius hippoglossoides)

In the absence of defined reference points and an accepted assessment the status of the stock cannot be fully evaluated. The stock has been at a low level for several years and it is a long-lived species, which can only sustain low exploitation. Indications from fishery independent surveys are that the stock has increased in recent years (Figure 4.3.25). During the last 15 years, average catches have been around 13 000 t (Figure 4.3.24). Given the state of the stock and the paucity of information, the fishery should not exceed 13 000 t until better information is available and firm evidence of a larger stock size has been obtained. In 2004-2006, catches were about 19 000 t, but declined to about 15 000 t in 2007 and 13 000 t in 2008.

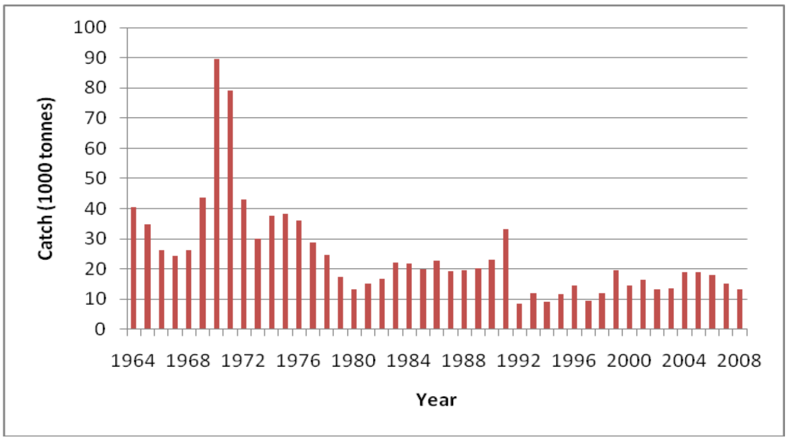

Figure 4.3.24. Northeast Arctic Greenland halibut; landings 1964-2008.

There is at present no accepted assessment for this stock, mainly due to age-reading problems and lack of contrast in the data. The age-reading issue is being addressed and should be resolved in future years, but corrections to past years are required.

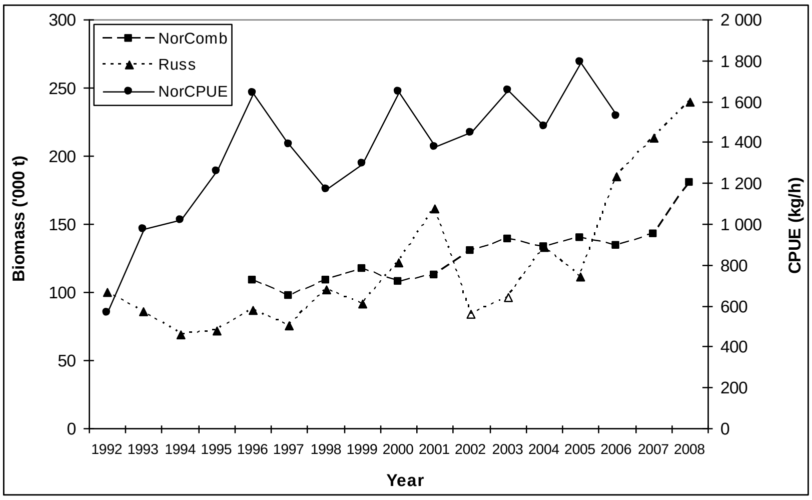

Figure 4.3.25. Northeast Arctic Greenland halibut; Biomass estimates from three surveys targeting Greenland halibut. NorComb is a combined index of Norwegian surveys covering most of the Barents Sea, Russ is the Russian autumn survey and NorCPUE is a survey covering the central adult area.

4.3.5.5 Capelin (Mallotus villosus)

The stock size is increasing. The spawning stock (Figure 4.3.26) of capelin in 2009 is predicted from the acoustic survey in September 2008 and a model, which estimates maturity, growth and mortality (including predation by cod). The model takes account of uncertainties both in the survey estimate and in other input data. For catch levels in spring 2009, below 390,000 t, the probability of having an SSB below 200,000 t is below 5 %. Only catches of mature fish have been considered. Based on the most recent estimates of SSB and recruitment ICES classifies the stock as having full reproductive capacity. The maturing component in autumn 2008 was estimated to be 2.5 mill t., and SSB 1st April 2009 is predicted to be at 0.54 mill t. The spawning stock in 2009 will consist of fish from the 2005 and 2006 year classes, but the 2006 year class will dominate. The survey estimate at age 1 of the 2007 year class is above the long-term average, and is the strongest since year 2000. Observations during the international 0-group survey in August-September 2008 indicated that the 2008 year class is strong.

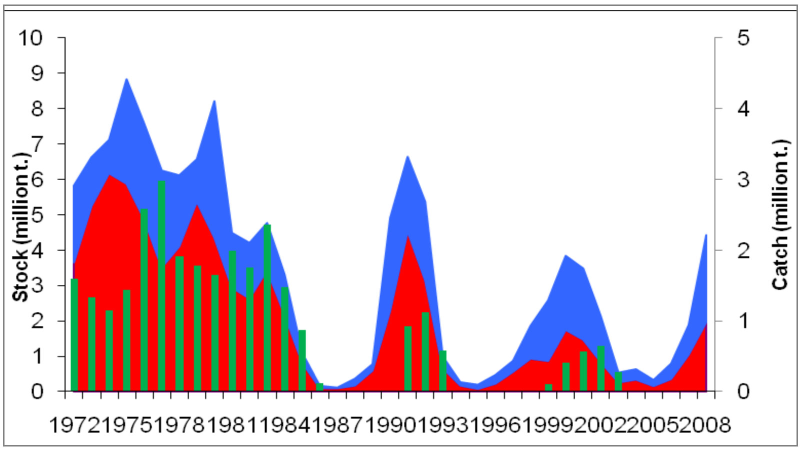

Figure 4.3.26. Barents Sea capelin. Total stock (blue area) and maturing component (red area) during autumn and total landings (columns), 1973–2008.

The estimated annual consumption of capelin by cod has varied between 0.2 and 3.0 million t over the period 1984-2008. 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, in 1992-1994, and from 2002-2005.

4.3.5.6 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 1998, 1999, 2002 and 2004 year classes dominate the current spawning stock which is estimated to 12.6 million t in 2009. Preliminary indications show that the year classes 2005-2008 are below average. Therefore the abundance of herring in the Barents Sea is believed to be at a relatively low level in 2009.

This stock has shown a large dependency on the occasional appearance of very strong year classes (Figure 4.3.27). In recent years the stock has tended to produce strong year classes more regularly. However, if strong year classes should become more intermittent, the stock is expected to decline.

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 ecosystem in the Barents Sea.

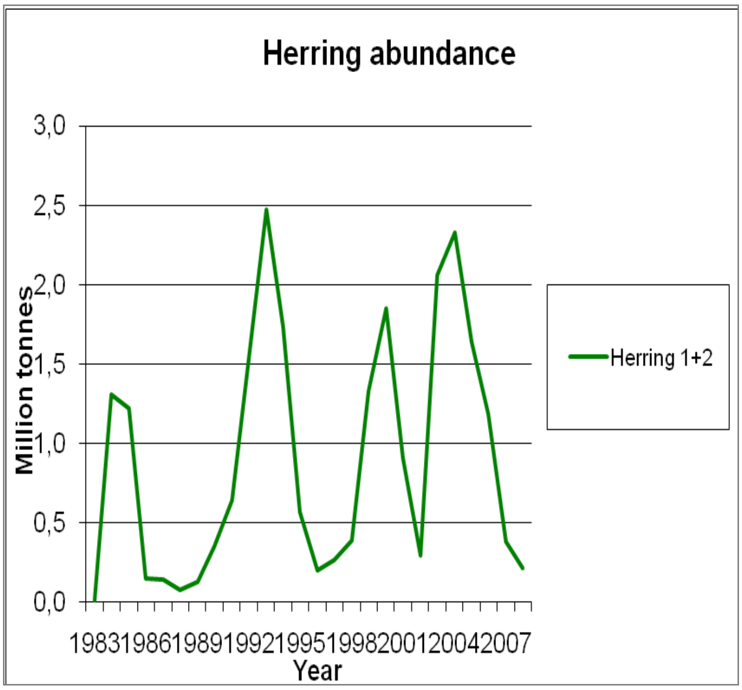

Figure 4.3.27 Abundance of age 1 and 2 Norwegian Spring-spawning herring (calculated by VPA). This is a good indication of the abundance of young herring in the Barents Sea.

4.3.5.7 Polar cod (*Boreogadus saida*)

The polar cod stock is presently at a high level (Figure 4.3.28). Norway took some catches of polar cod in the 1970s and Russia has fished on this stock more or less on a regular basis since 1970. The stock size has been measured acoustically since 1986 and the stock has fluctuated between 0.1-1.9 million t. In 2008, the stock size was measured to about 1.2 million t., which is equal to the estimate obtained in 2007. The natural mortality rate in this stock seems to be very high, and this is explained by the importance of polar cod as prey for cod and different stocks of seals.

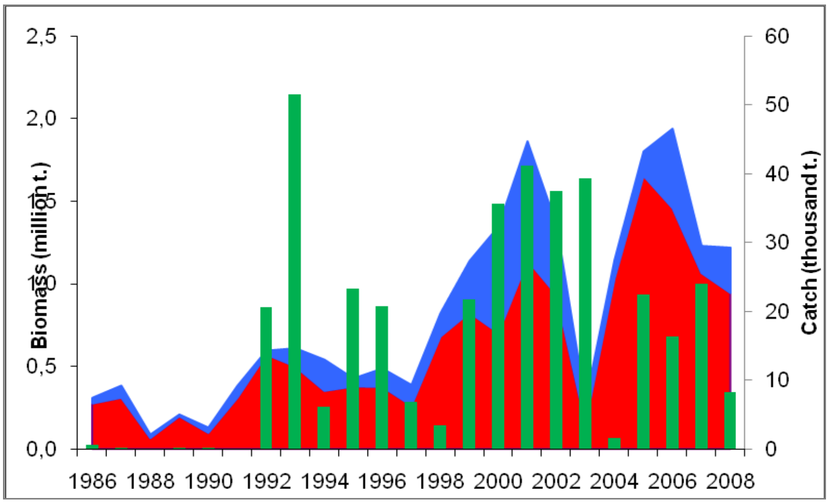

Figure 4.3.28. Polar cod. Stock size estimates obtained by acoustics, 1986–2008.

4.3.5.8 Blue whiting (Micromestisius poutassou)

Based on the most recent estimates of fishing mortality and SSB, ICES classifies the stock as having full reproductive capacity, but being harvested unsustainably. SSB increased to a historical high in 2003 but has decreased since, and is expected to be just above Bpa in 2009. The estimated fishing mortality is well above Fpa. Recruitment in the last decade appears to be at a much higher level than earlier, but has decreased in the last couple of years. Total landings in 2007 were 1.6 mill. tonnes, which is lower than in 2006. Blue whiting is not fished in the Barents Sea.

The high abundance of blue whiting in the Barents Sea (Figure 4.3.29) in recent years may be due to increased temperature. Blue whiting has been observed in the western and southern Barents Sea for many years, but never in such quantities, and never as far east and north in this area as in 2004-2007. In autumn 2008, the acoustic abundance of blue whiting was estimated to 0.1 million tonnes, which is much lower than in 2007. Thus, the abundance of blue whiting in the Barents Sea is expected to stay at a low level until the recruitment to the stock increases again.

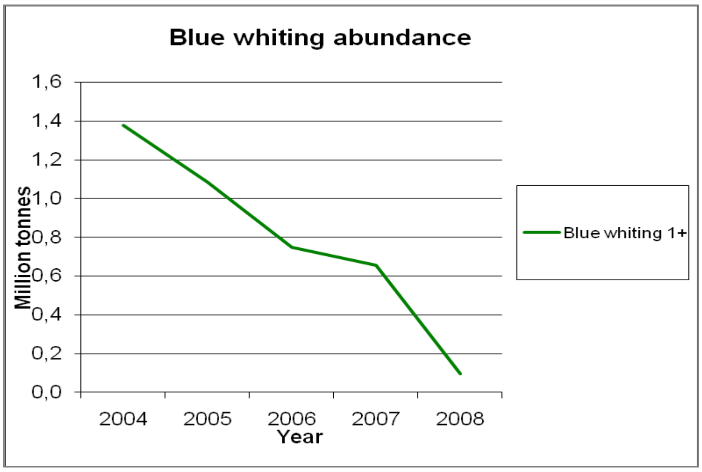

Figure 4.3.29. Blue Whiting. Acoustic abundance estimates from the ecosystem survey autumn 2004-2008.

4.3.5.9 Saithe (Pollachius virens)

Based on the most recent estimates of SSB, ICES classifies the stock as having full reproductive capacity. Based on the most recent estimates of fishing mortality, ICES classifies the stock to be harvested sustainable. Fishing mortality is stable and has since 1996 been below Fpa. The SSB (Figure 4.3.30) has since 1994 been well above Bpa. After a long period of low stock size, the stock recovered during the 1990s with the recruitment of several above-average year classes. The current estimated fishing mortality (0.20) is just above the lowest fishing mortality that would lead to high long-term yields (F0.1 =0.14). ICES evaluated a Harvest Control Rule (HCR) for NEA saithe in 2007 and concluded that it was consistent with the precautionary approach. Norwegian authorities implemented the HCR autumn 2007. This rule has the objectives of maintaining high long-term yield, year-to-year stability and full utilization of all available information on stock dynamics. It aims to maintain target F at Fpa = 0.35 and to keep the between year TAC change to within +/- 15%, unless SSB falls below Bpa when the management targets should change. The highest long-term yield was obtained for an exploitation level of 0.32, i.e. a little below the target F used in the HCR (Fpa), and ICES recommended using a lower value in the HCR. However, Norwegian authorities implemented the management strategy with a target F at Fpa = 0.35. This implies a TAC of 204 000 t in 2010 if a lower exploitation level still not is used.

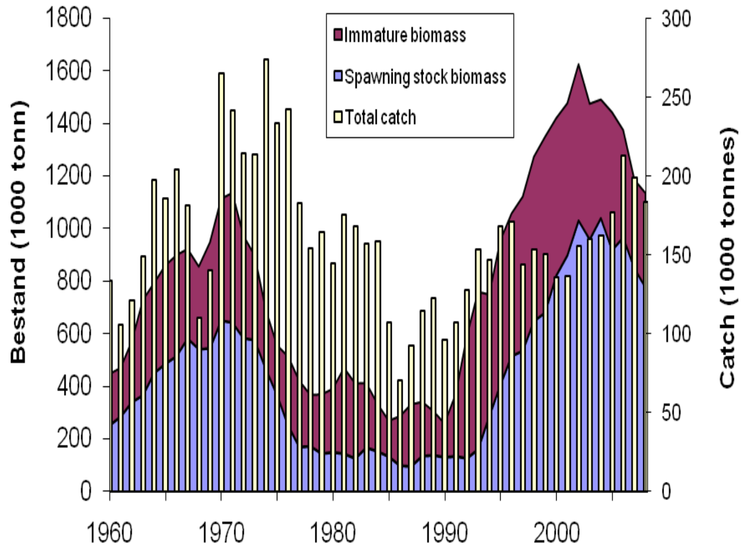

Figure 4.3.30. Northeast Arctic saithe, development of spawning stock biomass (blue area), total stock biomass (red area) and landings (columns).

In the Norwegian fishery, which at present accounts for more than 90 % of the landings, various gears are used, while other nations mainly use bottom trawl. On average over the last ten years about 40 % of the Norwegian catch originates from bottom trawl, 25 % from purse seine, 20 % from gillnet and 15 % from other conventional gears (long line, Danish seine and hand line). The gillnet fishery is most intense during winter, purse seine in the summer months while the trawl fishery takes place more evenly all year around.

4.3.6 Marine mammals

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High Arctic endemics occupying the Barents Sea Region include the polar bear, walrus, ringed seal, bearded seal, harp seal and hooded seal, white whale, narwhal and bowhead whale. All of these animals are associated with sea ice through much or all of their annual cycle and hence are currently a conservation concern because of the declines in arctic ice coverage over recent decades and predictions of continued declines into the future (see Chapter XX; 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).

Polar bears have a circumpolar arctic distribution. They are heavily dependent on sea ice for foraging and for transportation to and from terrestrial denning areas and a thick snow layer in maternity denning areas. They prefer first-year ice that develops over the shelf seas for hunting, where ice-associated seals that are their primary prey are most abundant (e.g. Derocher et al., 2002). Nineteen populations of polar bears are currently recognised, varying in size from a few hundred to a few thousand animals; the global population size is ~25,000 animals (IUCN, 2008). 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 whole Barents Sea Region, confirming the results of genetic analyses that suggested there is no geographic distinction between animals from Svalbard and Franz Josef Land (Mauritzen et al., 2002). Polar bears were exploited in the Barents Region from the late 18th century onward (Uspensky, 1969; Lønø, 1970; Prestrud and Stirling, 1994), but hunting was banned in Russia in 1956 and in Norway in 1973 due to overexploitation of the stocks. 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. Population declines are expected in coming decades for most polar bear populations, including that in the Barents Sea (Wiig *et al.*, 2008).

Walruses are distributed across the circumpolar Arctic, but two subspecies are recognised, 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, and in the southern Barents Region they occur in the Pechora Sea as well as the Kara Sea and recently (the last 6 years) they have been regularly observed in the White Sea as well (Klepikovsky and Lisovsky, 2005; Svetochev and Svetocheva, 2008; Zyryanov et al., 2008). The walruses in the northern Barents Sea comprise a single population of Atlantic walruses, that during the winter mating period occupies the ice between the two archipelagos, although individual animals seem to display considerable fidelity to their respective summering grounds (Freitas et al., 2009); the affinity of the animals from the Pechora, Kara and White Seas has yet to be resolved. Walruses are generally found in areas of shallow water (<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 the southern parts of the Barents Sea, extirpating them from the Norwegian mainland and reducing them throughout the Pechora and Kara Seas. Most walruses repatriating Svalbard are males, with females and calves only occuring routinely in the northeast corner of Svalbard; females are concentrated eastwards toward Franz Josef Land.

There is approximately 20,000-30,000 Atlantic walruses; ~2,500 of which spend the summer in Svalbard (Lydersen et al., 2008). Walruses in the southern areas of the Barents Sea in Russian territories are also thought to be increasing (Svetochev and Svetocheva, 2008; Zyryanov et al., 2008). However, the total population size of the whole Barents Sea is unknown as Russian areas have never been surveyed.

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 the sea ice, which is their exclusive breeding and haul-out platform. Except for during the fast-ice/breeding season, ringed seals in the Barents Sea can occur in water of virtually any depth, as long as ice is available for haul out. Their distribution and movements in summer are probably driven mainly by the availability of food (primarily pelagic and ice-associated prey) in combination with sea ice conditions (Eliseeva, 2008). The world population of ringed seals numbers in the millions, but few areas have been systematically surveyed. The Barents Sea population probably numbers close to 100,000 individuals, though adequate assessment data are only available from some of Spitsbergen's fjords, where the west/north coast stock contains 7,000-10,000 animals (Krafft et al., 2006). Ringed seal reproduction has been negatively impacted by recent poor ice years in Svalbard (2006, 2007 and 2008), and the poor production is bound to cause declines in the adult population when these cohort groups should have started contributing to production. Redistribution and declines in ringed seal abundance are expected based on forward-looking sea ice scenarios for the Barents Region (e.g. Kovacs and Lydersen, 2008).

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 and early summer, when they are breeding, and then moulting, and the sea-ice cover is restricted. Bearded seals can maintain holes in relatively thin ice, but avoid densely packed ice unless open-water leads are available. During winter, they concentrate near polynyas or in areas where leads are frequent, or they stay near the edges of the ice. 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). They are largely coastal animals. While bearded seals in some areas are thought to be resident within a small home range throughout the year (e.g. Eliseeva, 2008), bearded seals in other areas are thought to follow the retracting ice northward during summer and back again in 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 it probably numbers in the hundreds of thousands in the Arctic. In the Barents Sea, there certainly are thousands of bearded seals, but no systematic assessments have been conducted. Declines in sea ice coverage would be expected to have negative impacts of bearded seal abundance (e.g. Kovacs and Lydersen, 2008).

The white whale, or beluga whale, is the most numerous of the three resident, ice-associated arctic whales in the Barents Sea. Satellite-tracking of white whales in Svalbard in summer and early autumn showed a profoundly coastal distribution; tracking data from the late autumn and early winter suggest that they remain close to the same areas, penetrating deep into extensive ice. During summer they spend most of their time in association with glacier fronts in Svalbard, or moving between them (Lydersen et al., 2001). Aerial surveys and intensive long-term behavioural studies have been conducted on white whales in the White Sea. Some of the whales are thought to be resident throughout the year; however, there is also an influx in summer and outflux in winter, so some proportion of the White Sea population does migrate into the Kara and broader Barents Sea for 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). The 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 are poorly delineated in Russia (Boltunov and Belikov, 2002); but, White Sea numbers in summer average ~ 6,000 animals in recent years (2005-2007). 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 is likely to result in increased killer whale predation on white whales in northern waters and some prey shifting might be required if polar cod numbers decline. But, it is difficult to predict precisely how this species will be affected by climate change.

Narwhal inhabit the Atlantic Sector of the Arctic Ocean and 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 live in 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 shrimps. Maximum longevity is over 100 years of age (Garde et al., 2007). Little is known about narwhals in the Barents Sea. They do come into fjords in the north of Svalbard in summer and can be seen at the southern edge of the polar ice across the northern Barents Sea during summer, being most numerous near Frans Josef Land (Gjertz, 1991; Gorbunov and Belikov, 2008; NPI Marine Mammal Sighting Data Base). They are rare in the southern Barents Sea, but do occur in the Kara Sea (Gorbunov and Belikov, 2008). Three individuals that were satellite-tracked northeast of Svalbard remained close to Nordaustlandet in late summer, sometimes diving deep (maximum 545 m) into a trench in the northeast part of the Svalbard Archipelago (Lydersen et al., 2007). The global population size of narwhals is not known, but there is thought to be approximately 50,000 in the Northwest Atlantic Region. 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 on the Red Book of the Russian Federation. 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.

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 circulation system (with numerous vascular retes) for conserving heat. Moreover, their highly elevated blow-holes are thought to be an adaptation to breathing in cracks in the ice. 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 and Kara Seas to Franz Josef Land and perhaps beyond. Bowhead whales usually remain close to the southern boundary of winter ice. As the ice cover recedes, the whales move northwards and disperse in the pack-ice waters during spring, summer and autumn. Extreme overharvesting in the Barents Region in the 1600s-1700s came close to exterminating this population. The number of bowheads dropped catastrophically in the region by the mid-19th century (Shelden et al., 2001). After WWII only lone animals or small groups of whales were occasionally seen 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; 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 is presumably only in the tens (Christensen et al., 1992) or at most, in the low hundreds. The whales in this stock appear to exhibit the same seasonal patterns that were followed in spring hundreds of years ago when the population was numerous; at least they are still found in “Whalers Bay” in the Fram Strait in April (Wiig et al., 2007). Near future distribution and abundance of bowhead whales in the Barents Region depends largely on climate change impacts on calanoid copepods, their primary prey. Their extreme longevity, slow maturity and low reproductive capacity leave them vulnerable to negative aspects of environmental change (George et al., 1999; Kovacs and Lydersen, 2008).

White-beaked dolphins are the only dolphin to remain in the Barents Region on a year-round basis. They are found throughout the North Atlantic, primarily in shelf waters, but they can also inhabit offshore areas of intermediate depths. During summer, they can be found north to the ice edge. Their ecology in the Barents Sea area is poorly known. 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 by the Marine Research Institute during the last 5 years, suggest that the distribution and abundance of white-beaked dolphins seem to be quite stable.

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 (see below). 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). 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 39^{o}E, 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. There is also a small group of harbour seals in Svalbard largely restricted to the west coast of Spitsbergen. The Svalbard stock contains ~1000 animals (Lydersen and Kovacs, 2001) and 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 (Syryanov, 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 and this stock also is subject to mortality via entanglement in gill nets and other fishing gear and other fisheries-related mortality. Current levels of total mortality are thought to be unsustainable.

Grey seals occur only in the North Atlantic, south to Maine in the West Atlantic and to the Baltic Sea in the East Atlantic. The major population centres are located around the British Isles and on Sable Island off the east coast of Canada. Baltic and Norwegian populations are genetically different; and so are the East and West-Atlantic grey seals. Even subpopulations within the Barents Sea Region show significant genetic variation (Frie and Kondakov, 2008). Although larger than harbour seals, they share their coastal habitat, though they spend longer periods of time at sea during part of the year. This species utilises an amazingly broad variety of habitats. Within the Barents Sea, grey seals occur along the north coast of mainland Norway, and eastward along most of the Murman coast of the Barents Sea; they are occasionally seen in the White Sea in summer. 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 the low numbers of grey seals, hunting bounties were instituted in 2003 to reduce numbers further. 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). Current hunting levels in the Norwegian Barents Region are not sustainable.

The harbour porpoise is a small odontocete with a wide geographic range that includes most temperate and boreal waters of the Northern Hemisphere. It is the smallest cetacean in the

Barents Sea, and it is largely a coastal species. A single harbour porpoise has been sighted repeatedly on the north coast of Spitsbergen during the last few summers (2005-2007), often in association with groups of white whales (NPI Marine Mammal Sighting Data Base; Kovacs and Lydersen, 2006). They normally occur in small groups and only rarely form 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 Goos Banks (Skern-Mauritzen et al., 2008). The Barents Sea population is believed to consist of about ~11 000 individuals (Bjørge and Øien, 1995). In order to sustain current levels of by-catch, immigration of porpoises from adjacent waters is required in this region. The sustainability of this situation is difficult to predict because migration and population structure and general ecology of porpoises in Norwegian coastal waters are not well documented (Bjørge, 2003).

Harp seals are migratory, pelagic and much wider ranging than ringed seals, bearded seals or walruses and they have a more pelagic mode of life (Haug et al., 1994). Three different populations inhabit the North Atlantic: one in the Northwest Atlantic off Canada's east coast; one in the Greenland Sea (West-Ice), which breeds and moults just north of Jan Mayen ; and the final stock, the East-Ice stock, which congregate in the White Sea to breed. During spring (February-April), harp seals whelp on the pack ice and then adults and subadults moult north of each respective whelping location after a lapse of ~4 weeks. Some animals from both Northeast Atlantic stocks spread into the Barents Sea in the summer and autumn months overlapping in their range; their specific distribution in the Barents Sea is mainly dependent on the distribution of drifting pack-ice (Folkow *et al*., 2004, Nordøy et al., 2008). The West-Ice seals also spread through the drift ice along the east coast of Greenland, from the Denmark Strait or farther south, towards Spitsbergen. The southward migration towards the breeding areas begins in November-December. The most recent estimate for the West-ice group is ~750 000 (2008) and the population is thought to be stable or increasing (ICES, 2008). According to Dorofeev (1939, 1956), aerial surveys performed on the 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, 2008), and the population was probably reduced to 1.25-1.5 million individuals in the 1950s (numbers based on aerial surveys on the moulting (shedding the hair) grounds in 1952-1953 and in 1959; Surkov 1957, 1963), see also Skaug *et al*. (2007). Recently, pup production has been in decline, dropping from over 300,000 in 1998-2003 to 123,000 in 2008 (ICES, 2008). The 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 fish resources (particularly capelin declines) and hunting levels may all have contributed to the observed reductions (Chernook and Boltnev, 2008; Chernook *et al*., 2008; Shafikov, 2008; Vorontsova et al., 2008; Zabavnikov *et al*., 2008).

Hooded seals form one stock in the Northwest Atlantic and another in the Northeast Atlantic though recent genetics work suggests 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 the pack-ice north of Jan Mayen. During the 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). Back-calculation using a population model indicates a possible stock size in the West Ice of 700,000 animals shortly after WWII, whereas current (2007) size of the stock is estimated to be ~82 000 animals (ICES, 2008). Because of the significant declines the hooded seal in the West Ice, this species is now on the Norwegian Red List, as well as the International Union for Conservation of Nature (IUCN) Red List and the quota has been set to zero since 2007 (ICES, 2008).

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). The registered declines in West Ice hooded seals and White Sea harp seals are both thought to be related, at least in part, to less stable ice conditions and other ecosystems shifts related to climate warming.

Among the toothed whales, the long-finned pilot whale, the killer whale, the northern bottlenose whale and the sperm whale are summer visitors to the Barents Sea. The Northeast Atlantic population of long-finned pilot whales numbers some 780,000 individuals (NAMMCO 1998), but only a very small (and unknown) part of this population enters the Barents Sea. Pilot whales must therefore be considered stragglers along the Norwegian coast and in the Barents Sea. Sperm whales are associated with deeper areas along the shelf edge north to Spitsbergen, but are occasionally observed north to the ice edge and on the shelf. The other species are more frequent in the southern Barents Sea. Killer whales occur in all the oceans of the world and most seas, but their relative scarcity and sporadic occurrence make them difficult to census in the Barents Region. 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 ~7000 animals in this area. Killer whales have been sighted with increasing frequency in Svalbard waters in recent years, usually at the shelf edge, and have been seen as early as March at close to 80^{o} N in 2008 (NPI Marine Mammal Sighting Data Base). 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 until 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, the northern bottlenose 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. 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 (see Christensen et al., 1992). IMR ecosystem survey indicates a stable distribution of individuals along the shelf edge.

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 (Skaug et al., 2004). The 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 (see Skern-Mauritsen et al., 2008). In late summer in the northern Barents Sea, the distribution of baleen whales seems to be tightly linked to the capelin foraging migrations. Fin, humpback and minke whales generally occur along the northern front of the capelin migrations, avoiding areas with high capelin density. Thus, these baleen whales likely forage on zooplankton, and seek areas not yet reached by the capelin. This implies that competition with capelin might be quite important in determining the baleen whale distributions in this area. At the same time, in the southern Barents Sea, fin and minke whales aggregate in areas with high densities of herring and blue whiting, suggesting predation on pelagic fish in this area (Skern-Mauritzen, unpublished data). The late-summer distribution of baleen whales has varied little during the last few years. However, in 2008 the number of minke, fin and humpback whales observed during the ecosystem cruise dropped by 50-70% compared to the numbers observed in 2007. The numbers must be corrected for “effort” before any firm conclusions on density reductions can be made, but preliminary exploration of the data suggests that the reduction in sightings is not solely due to a reduction in observer effort. One can only speculate as to the reasons for such a decline. Baleen whales are long-lived species, and reductions from one year to another are almost certainly a result of redistribution rather than reductions in population sizes. If these whales are competing for food with capelin, such redistributions could be linked to the current increase in the capelin stock. Capelin is one of the preferred prey species for baleen whales. However, being gulp feeders, they are dependent on rather high capelin densities for efficient foraging. Capelin densities reached in 2008 may not have been sufficiently high for baleen whales to switch from zooplankton to capelin, although we do expect this to happen if there is a sufficient increase in the capelin stock. Norwegian vessels harvest approximately 600 minke whales annually from the North, Norwegian and Barents Seas (Skern-Mauritzen et al., 2008).

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, when they are breeding, they are thought to fast. In the Barents Sea, fin whales generally inhabit deeper areas along the continental slope, west of Spitsbergen and in the Storfjorden trough, though in recent years that 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 thought 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).

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. They probably number 600-1500 in the whole North Atlantic. Several animals have been sighted each of the last few summers between Bear Island and Kongsfjorden, Svalbard at the shelf and pack-ice edges (NPI Marine Mammal Sighting Data Base).

Other small cetaceans that frequent the Barents Sea, bottlenose dolphins, common dolphins and white-sided dolphins can be seen in the southern Barents Sea, particularly along the shelf break and over oceanic banks and ridges, but must be considered vagrants in the region. Assessment of the population size of these small cetaceans in the Barents Sea is complicated by the fact that dolphins are often generically recorded as "springers", rather than being documented at the species level. But, it is thought that white-beaked dolphins dominate in terms of abundance throughout the Barents Sea.

Expected increases in productivity within the Barents Sea, with declining sea ice coverage and warmer temperatures in coming decades, is likely to result in increased abundances of migratory cetaceans into the area. The distribution of these animals is largely determined by prey availability.

4.3.7 Seabirds

H. Strøm (NPI), M. V. Gavrilo (AARI), J. V. Krasnov (MMBI) and G. H.. Systad (NINA)

The numbers of seabirds breeding in the Barents Sea Region have changed dramatically over the last 50 years. Increase in numbers of several species were associated with a recovery from an excess harvest of eggs and adults in the first half of the century, e.g. on Svalbard and Novaya Zemlya (Barrett and Krasnov, 1996). The changes seen in several populations in the second half of the 20th century can be explained by several factors. After 1950 there have been great fluctuations in all three primary prey fish stocks; herring, capelin and polar cod. The spawning stock of the herring declined rapidly in the 1950s and 1960s from more than 14 million tonnes in 1950 to near zero in the early 1970s but, after a fishing moratorium, recovered in the late 1980s reaching 12,9 million tonnes in 2009. The capelin stock has also fluctuated greatly with minima in 1986/87, 1994/95 and 2003/04, and peaks in 1991/92 and 2000/01 (7.3 and 4.3 million tonnes respectively; Bakketeig et al., 2005). The polar cod stock has increased in size since the beginning of the acoustic surveys in 1986, from about 0.5 million tons in the 1990's to about 1.2 million tons in 2008 (Anon, 2009).

Altogether 15 species were monitored in 2008 at 18 different locations in the western and southern Barents Sea and the White Sea. The 2008 season was characterized by decrease in the the breeding populations of several species in the western Barents Sea, especially along the mainland coast of Norway, from Nordkapp and westwards. The decreases were especially pronounced for the pelagic feeding species such as northern fulmar, black-legged kittiwake, razorbill and common guillemot. For these species the reductions in the breeding population from 2007 to 2008 were between 6% and 70% at some monitoring sites (e.g. Hjelmsøya at the coast of Finnmark; Lorentsen and Christensen-Dalsgaard 2009). The breeding numbers of some of the coastal feeding species such as the European shag and the black guillemot also dropped (Lorentsen and Christensen-Dalsgaard 2009). Along the Murman coast, the situation was contradictory. The breeding population of black-legged kittiwake declined by an average of 17% from 2007 to 2008 both in Western and Eastern Murman (Gorodetsky and Krutik Capes). At the same time, breeding numbers of common guillemots increased by 10–14% both in Western and Eastern Murman colonies (Gorodetsky Cape and Dvorovaya Bay; Krasnov unpubl. data).

The low number of birds attending both Norwegian and Russian colonies in 2008 do not only reflect low adult survival between years, but may also have been the result of poor environmental conditions with reduced body condition and low colony attendance as the result. The 2008 season was also characterized by a total breeding failure for many species in Norway: again most pronounced in the pelagic feeding species, but also coastal feeding species such as the great black-backed gull, the herring gull and the lesser black-backed gull that were not able to raise chicks in many colonies in North Norway in 2008. Low productivity was also recorded in colonies on the western Murman coast where e.g. the black-legged kittiwake laid small clutches (Gorodetsky Cape, Krasnov, unpubl. data).

This breeding failure was not unique for the southern Barents Sea. The breeding seasons of 2008 were some of the poorest ever recorded in the northeast Atlantic. Many seabird colonies in the UK, Faeroe Islands, Iceland and along the Norwegian coast experienced near total breeding failure (Lorentsen and Christensen-Dalsgaard 2009). And for some of the species like the black-legged kittiwake the decline is more or less circumpolar in its extent).

In contrast, many seabird populations in the White Sea (Onega Bay) did well in 2008 (Cherenkov et al. 2008), with an annual increase in breeding numbers from 2–5 % in herring and lesser black-backed gulls up to 25–30 % 25–30 % in arctic tern and common eider. In contrast, the black guillemot population declined slightly (ca. 3%).

The decrease in the breeding population and the very poor reproduction in 2008 reflect long term trends for several of the most numerous species in the Barents Sea. The Barents Sea population of common guillemots is now ca. 104,000 pairs, which is a large reduction since the first population estimates were made in the 1960s in the North Norwegian colonies (Brun 1969, Barrett and Golovkin 2000, Barrett et al. 2007). The population of the common guillemot has declined dramatically in all colonies west of the North Cape. Most alarming is the collapse of the colony on Hjelmsøy from what was the largest colony of approximately 220,000 individuals in 1964 to less than 5000 individuals today. Some of the colonies can today be considered as being seriously threatened with extinction because of too few pairs for the colony to be viable (Erikstad et al 2007, Barrett and Golovkin 2000). The Norwegian colonies of common guillemots east of the North Cape and the Russian colonies along the Murman coast have either fluctuated around stability or increased during the same period, at least until 1986 (Barrett and Golovkin 2000). In 1986-1987 there were huge declines on all colonies in the region, including Bear Island, where the population dropped from 245,000 to 36,000 pairs from one year to the next. Numbers have since increased in the Norwegian colonies east of Nordkapp and Bear Island, but the numbers on Bear Island was in 2006 still less than half of the estimated population in 1986 (Strøm 2007). In both Western and Eastern Murman a steady decline in the breeding population of common and Brünnich' guillmot has been observed since the mid-1990s with a major drop in Western Murman in 2000–2002 (Krasnov, unpubl.).

The initial dramatic reduction in the common guillemot population was most likely mainly the result of drowning in fishing gear, egg harvesting, hunting and food shortages. West of Nordkapp, the annual drowning of breeding adults during the long-line and drift-net fisheries for Atlantic Salmon Salmo salar was probably the most significant single factor causing declines in what were once the largest colonies in Europe in the 1960s and 1970s (Brun 1979, Strann et al. 1991). These fisheries were banned in the early 1980s and 1989 respectively, but birds are still sometimes reported drowned in nets set for cod. Some colonies have declined so much that they may now be on the verge of extinction with seemingly too few pairs remaining for the colonies to be viable (Erikstad et al 2007). Although drowning in fishing gear is now considered a minor threat to adult birds, numbers along the Norwegian Sea coast and at Hjelmsøya (one of the two colonies monitored in the Barents Sea) continue to fall steeply (98-99% declines at Vedøy in Røst and at Hjelmsøya between the early 1980s and 2005). While the breakdown of the social structure of the colonies (with single or very few birds on individual breeding shelves) is thought to contribute to the further decline, there is now compelling evidence that the present large population of white-tailed eagles (which has gradually recovered since it was legally protected in 1968) is exacerbating the situation. Their activity has resulted in some populations (e.g. Røst, Bleiksøya, Hjelmsøya) being forced to breeding under cover, for example in large cracks or stone screes, to avoid predation. Although still poorly covered by existing monitoring, birds breeding in such habitats are much more productive than those on exposed cliff ledges (Lorentsen et al. 2009).

The black-legged kittiwake has declined significantly at rates varying between 1-5% p.a. since the 1980s. This was after a increase in North Norway (and probably other parts of the Barents Sea, e.g. Novaya Zemlya) at a rate of ca. 1% p.a. in the 1960s and 1970s, and this increase continued into the early 1980s, at least in eastern Finnmark where the increase was as high as 4-8% p.a. in 1970-1983 (Brun 1979; Krasnov and Barrett 1995; Barrett 1985). The rate of decline has accelerated since the mid-1990s, up to 10-15% p.a. in some colonies (Barrett 2003; Lorentsen and Christensen-Dalsgaard 2009) resulting in average decreases of 6% p.a. in the colonies in the southwestern Barents Sea. Numbers of apparently occupied nests in monitoring plots on the key sites Runde, Vedøya (Røst), Hjelmsøya and Hornøya decreased by 75%, 50%, 75% and 50% respectively between the early 1980s and 2008 (Lorentsen and Christensen-Dalsgaard 2009). However, the decline is not so evident on Bear Island and Spitsbergen, were the population has been more or less stable after a drop in 2003 (Strøm 2006). On the Murman coast large fluctuations in breeding population numbers have been observed during recent decades (Krasnov et al. 2007). Reproduction success was quite low during last decade in all monitored Murman colonies.

Little is known about the causes of the kittiwake decline, but several authors have reported capelin to be the preferred food of black-legged kittiwakes breeding in East Finnmark, and have suggested that large capelin stock fluctuations (including several collapses) in the Barents Sea (Gjøsæter 1998) may be having negative effects on the population (Furness and Barrett 1985, Krasnov and Barrett 1995, Barrett 2007). For Murman colonies it was found earlier that kittiwakes and guillemot breeding numbers depended to a great extent on the size of capelin spawning stock during the winter-spring season, while their reproduction success depended on summer aggregations of herring, sandeel or capelin (Krasnov et al. 1995).

Kittiwake diet composition over the past two decades in Murman colonies was very diverse and variable with typically large proportion of small crustaceans which suggested poor feeding conditions for this species (Krasnov unpubl.). There is also evidence that increasing harassment from white-tailed eagles in many colonies along the Norwegian mainland has caused repeated local breeding failures and declines in black-legged kittiwake numbers (Barrett 2003; Anker-Nilssen and Aarvak 2006). The seemingly more stable populations in Svalbard and Kola Peninsula may be due local access to capelin or to alternatively prey.

A considerable decline in puffin populations has been observed on the Ainov Islands, Western Murman, one of the biggest colonies at the species easternmost range limit. The colony numbered several thousand pairs in the early 1990s, and dropped to only ca. 500 pairs in 2008 (KSNR and Krasnov, unpubl.). Human impact is considered to be the major driving force for the seabird population dynamics in Murman colonies, especially through commercial fishery which acts through dramatic changes in trophic conditions for seabirds. Generally, a low capelin stock in the Barents Sea provide very unstable food resources for the seabirds especially during spring season.

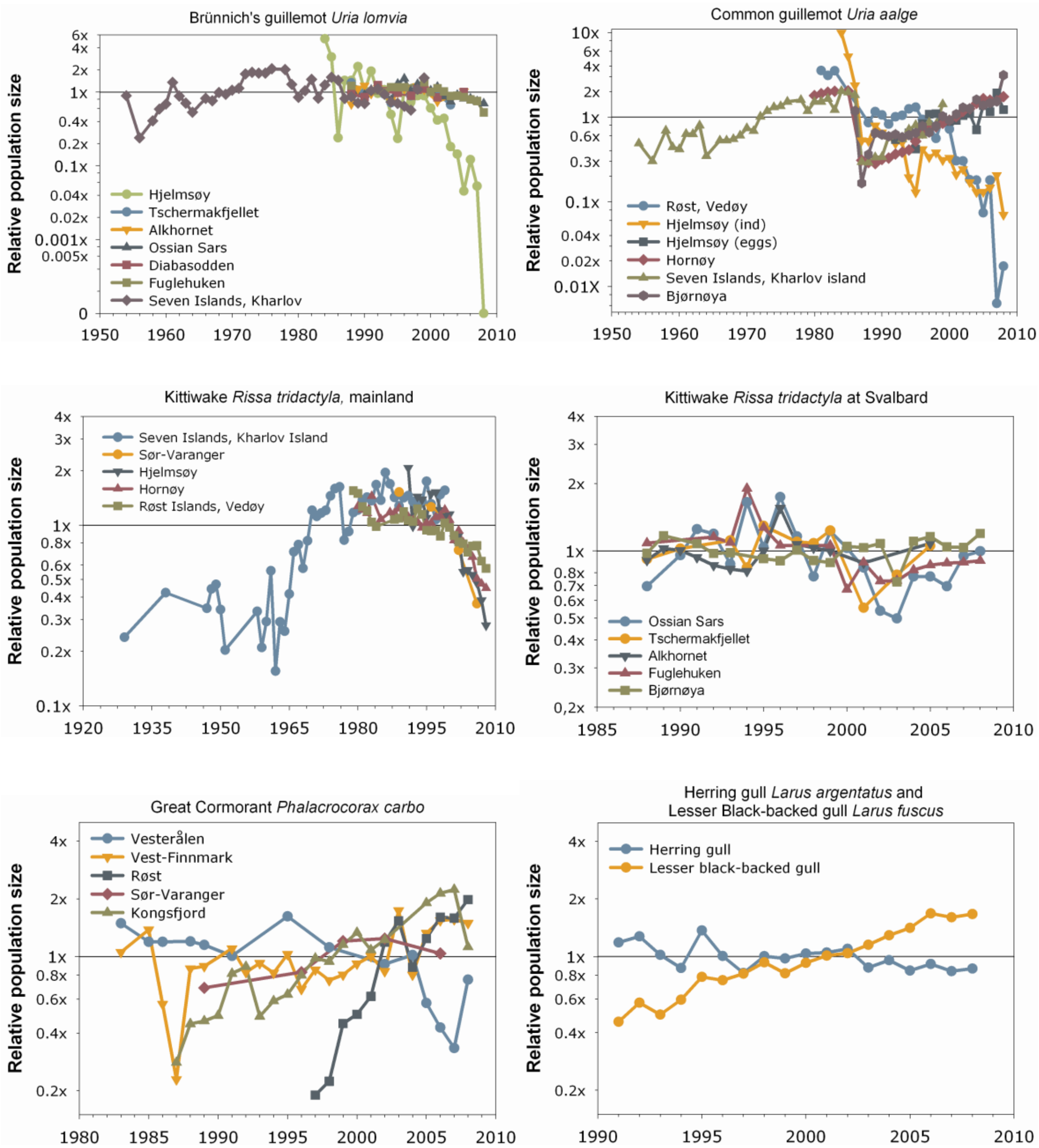

Figure 4.3.31. Trends in some seabird species monitored in the Barents Sea. Source: The Seabird Colony Registry of the Barents and White Seas and the Norwegian Institute for Nature Research.

4.3.8 Rare and threatened species

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This is the first joint Barents Sea report including a separate chapter on species requiring particular attention. This topic is restricted to fish, mammals and birds in this issue of the status report. The goal for future reports is to include a far broader spectre of taxonomic groups, more information on knowledge gaps, and also a more complete integration into the ecosystem interaction and ecosystem management chapters.

4.3.8.1 Fish

The actual area is inhabited by 28 fish species which are either on the Global Red List (8 species), or on the Norwegian Red List (25 species). Among these 13 are DD species, i.e. no scaled evaluation can be done because of lack of knowledge, but the species would probably be on the red list if adequate information had been available. When considering the marine fish species on red lists and threats, there seems to be three main groups of impact factors to be considered: (i) fisheries (catch and by-catch), (ii) environmental deterioration (pollution, habitat destruction), and (iii) climatic changes. Fisheries are by far the most important impact on the red listed species today, but climatic changes can be equally or more important – and less controllable – in the future.

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

- *Squalus acanthias*. ICES considers spurdog in the entire area from the Barents Sea in the north of Biscay in the south belonging to the same population. ICES catch statistics show a steady and marked decline since 1973 (about 33 000 tonnes) to 2003 (in 5000 tonnes) (ICES 2006a. ICES 2006b. Jones and Ugland, 2001). 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 eel (*Anguilla anguilla*). This species is not considered further here because it is anadromous and of marginal importance in the Barents Sea.

And five species are classified as VU, vulnerable,.

- *Lamna nasus*, Porbeagles have a long life expectancy and low reproductive ability. It is very vulnerable to overfishing. Reported catches have fallen from over 1000 tons in the 1960s, to about 20 tons in 2002. ICES recommends no fishing of this species and it is assumed that it will take at least 25 years rebuild the stock, even with a minimum capture. (Kohler, Turner, Hoey, Natanson and Briggs, 2002. ICES 2006b)
- *Molva dypterygia* exists in the entire area and are fished commercially (ICES 2006f). The Norwegian catches have been reduced from more than 2000 tons in 1960 to less than 500 tons in 2004. Fisheries directed for blue ling is now stopped and it is only taken as a by catch in the ling fishery. The closely related ling (*Molva molva*) is listed as 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 ICES (2006d). Both species has decreased considerably, probably due to overfishing. ICES consider both species to have reduced reproductive capacity, and they therefore need protection to allow the stocks to rebuild.
- *Ammodytes marinus* This species is most important in the North Sea, but are also found along the coast of northern Norway and in the Barents Sea (Holland, et al. 2005. ICES 2006e). This species is classified as VU on the red list mainly due to overfishing in the North Sea.
- *Gadus morhua,* cod, and *Melanogrammus aeglefinus*, haddock, are on the international red list, but none of them are 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 (ICES 2006d).

In addition to *Molva molva*, mentioned above, *Hippoglossus hippoglossus*, *Somniosus microcephalus*, *Theragra finnmarchica* and *Trisopterus esmarkii* are listed as NT, near threatened, on the Norwegian red list, and *Chimaera monstrosa* is listed in the same category on the international red list.

Among these species *Trisopterus esmarkii* and *Chimera monstrosa* is of minor importance in the Barents Sea.

The assessment of *Hippoglossus hippoglossus* as NT on the red list is based on the development of the Norwegian catch statistics over the last 3 generations (45 years). North of 62^{o}N population has increased again during the last 10-year period, and there the recruitment seems to be good. Still halibut is considered threatened by overfishing because of long generation time.

According ICES the population of the once common Greenland shark, *Somniosus microcephalus,* in the Northeast Atlantic is now very low, and are rarely caught and registered. The species is widespread in the cold ocean in the northern hemisphere, but its biology poorly known. 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 (ICES 2006b).

Fewer than 60 individuals of *Theragra finnmarchica,* which according to resent studies may be a stock of *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 spawned.

4.3.8.2 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, 15 are included in The Red Book of the Russian

Federation (2001) and 8 extant species are on the endangered species list of Norway (plus the recently extinct northern right whale stock). The anthropogenic factors that are thought to be most harmful for marine mammals are fisheries interactions, pollution and climate warming. The latter phenomenon is a particularly acute problem in the Arctic, and it is a serious threat factor for all ice-associated marine mammals. Increasing levels of tourism in Svalbard might also pose some 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 (Table 2.4.2; Aars et al., 2009); Population trends are currently unknown.

Walruses were dramatically overharvested in Svalbard in the 1800s and early 1900s, with only a few hundred animals remaining when they became protected in 1952. Walrus populations were also depressed by hunting in the southern parts of the Barents Sea, extirpating them from the Norwegian mainland and reducing them throughout the Pechora and Kara Seas. The trend in the numbers of walruses in the Barents Sea has definitely been positive in recent decades, though the rate of increase cannot be accurately assessed because of the lack of trend data. Walruses in the southern areas of the Barents Sea in Russian territories are also thought to be increasing (Svetochev and Svetocheva, 2008). The total population size of the whole northern Barents Sea is unknown as the Russian areas have never been surveyed.

Little is known about narwhals in the Barents Sea. They do come into fjords in the north of Svalbard in summer and can be seen at the southern edge of the polar ice across the northern Barents Sea during summer, being most numerous near Frans 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 certainly less numerous than white whales in this area.

Extreme overharvesting in the Barents Region in the 1600s-1700s came close to exterminating Spitsbergen stock of bowheads. 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.The abundance trend of 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 the 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 accidentally caught in coastal gillnet fisheries to an extent that may be unsustainable locally (Bjørge & Godøy, 2009), but the population structure of porpoises in the Barents Sea and North 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 in 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 hence are 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 populations of coastal-living seals in the southern Barents Sea because of policies aimed to reduce the 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, but little is known regarding its consequences. Industrial development including oil drilling and transport, as well as other sorts 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 PCB (see chapter 2.5.2).

Other ecosystem changes that can affect marine mammals include changes in food webs. The winter/spring harp seal invasions to coastal areas off northern Norway resulting from shortages of capelin, polar cod and herring serve as useful examples. In addition to consuming fish, the migrating seals caused substantial damage to gill-net catches and the nets themselves. They probably also caused the emigration of commercial fish species from traditional fishing grounds to deeper waters that 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 sea mammals in arctic regions are likely to be profound for endemic species. If the 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 be shifted pole-ward, and if the loss of sea ice is as dramatic as is 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, perhaps result in the extinction 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 the 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 consequences in the long-term for polar bears, considering that 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, the ice-living seals are highly dependent on the nature and extent of sea ice, whether for pupping, moulting or resting, and for some species, also foraging 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 the 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 prey-shift. 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 food web of the region. 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 changes is uncertain, but climate change is likely to have negative implications for the species that are endemic to the High Arctic. The uncertainty of cetacean responses is linked primarily to the uncertainty of future prey availability, in combination with our current lack of understanding of their linkage 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 of course makes them particularly vulnerable. They are dependent on calanoid copepods and euphausiids for food and changes in sea-ice conditions are likely to have large impacts on bowhead whale foraging. It is not known whether this species could survive in ice-free waters. Narwhal and beluga also currently spend much of their time in association with sea ice and are known to forage at the ice edge and in cracks in the ice. But the two species also do 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.

The other cetaceans that regularly frequent Svalbard waters avoid ice-covered area. Pilot whales, white-beaked dolphins, northern bottle-nosed whales fin whales, humpback whales, 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 risks posed by climate change to arctic marine mammals include the increased risk of disease in a warmer climate; the 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, and stronger impacts of shipping along the Northeast Passage and development (in particular petroleum development in the Barents Region) 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.

4.3.8.3 Seabirds

Several of the seabird populations in the Barents Sea region are of international importance. The most numerous 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 - in Svalbard and Franz Josef Land.

Among more than 30 seabird species breeding and wintering in the Barents Sea region, there are seven Red-listed species including two from the global list (IUCN, 2008), six from Norwegian Red List and three from the Red Data Book of the Russian Federation. Besides, there are four more species listed in the Annex to the Red Data Book of the Russian Federation that are of concern. The only species listed in all three categories of the Russian Red lists is the ivory gull . Major threats likely limiting population development of the Red-listed seabird species are: (i) - fisheries (competition for the resources and by-catch in gill-nets); (ii) - environmental deterioration (pollution, habitat destruction and disturbance); (iii) - climate change (Anker-Nilssen et al., 2000). Fishery 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 might become more important in the future (currently it is considering important for the ivory gull only). Since seabirds are migratory species, causes of their unfavourable population status might lie beyond the Barents Sea region boundaries.

The Steller's eider *Polysticta stelleri* is classified as globally threatened and is thus a species of global conservation concern (Tucker and Heath, 1994). It is listed as vulnerable by IUCN (2008). Large numbers of this rare and declining seaduck winters along the coast of Finnmark and the Kola Peninsula in significant numbers (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 the Norwegian wintering areas (Systad unpublished data). The status for the species is uncertain, and needs to be followed closely.

The ivory gull sporadically breeds in Arctic archipelagos (ca. 25% of the world population), Greenland birds migrate through the area. 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 and supposed 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 ice edge retreated to the north. This is supposed to be the major reason for the abandonment of the breeding colony on Victoria Island. In other part of the breeding grounds population is likely to fluctuate in numbers and alternate it distribution patterns. Species is found to have high (Hg) and very high (DDE and PCBs) loads of contaminants. No data on reproduction parameters, food availability or migration patterns dynamics are available. Population numbers and local breeding distribution as well as food availability and reproduction parameters are expected to fluctuate in future according to local ice and snow conditions.

The white-billed Diver *Gavia adamsii* (Red list of RF) breeds sporadically in single pairs in the Russian part. Most of the East Atlantic Flyway population winters in coastal waters off Norway and some few in Russia (off Kola Peninsula). No data is available on the population trend, habitat dynamics or key biological parameters. No reliable data are available to establish any future projection for the breeding period, but some data exists for the wintering distribution in Norway (www.seapop.no).

European shag *Phalacrocorax aristotelis* is red-listed in Russia as rare species. Breeding grounds along the Murman coast is the only Russian breeding area and the easternmost border of the species range. Breeding population is estimated at 350-400 b.p. with positive long-term population trend and breeding range expansion during the period of 1930s - 1980. Most recent (last decade) observations revealed slight decrease at the easternmost part of the area (East Murman). Food availability varies between years and affects local distribution of breeding birds, annual involvement in breeding performance and reproductive success. Reproduction parameters and local breeding distribution are expected to fluctuate in relation to food availability. In Norway, the mainland population of the common guillemot *Uria aalge* is listed as critical endangered (CR), whereas the black-legged kittiwake, the common tern *Sterna hirundo* and the Atlantic puffin are listed as vulnerable (V; Kålås et al., 2006). In Svalbard the ivory gull *Pagophila eburnea* is listed as endangered (E) and the common guillemot listed as vulnerable (Kålås et al., 2006). No other marine birds are listed in the three top categories (CR, E or V) either in Norway (including Svalbard) or in Russia (Kålås et al., 2006). In Norway several seabird species are listed in the two lower categories in the red list; near threatened (NT) and data deficient (Table 2.4.7).

Norwegian responsibility species, with a minimum of 25% of the European population breeding or wintering in Norway, includes three breeding populations of seabirds (great black-backed gull *Larus marinus*, black-legged kittiwake and atlantic puffin), and eight wintering species/populations (great northern diver, great cormorant *Phalacrocorax carbo*, European shag *P. aristotilis*, Steller's eider, king eider, red-breasted merganser *Mergus serrator*. All ten species/populations are within the Barents Sea region all year round or in one or more seasons. Russian responsibility species, with a minimum of 25% of the European population breeding or wintering in the Russian part of the Barents Sea, includes breeding populations of ivory gull and king eider, and wintering populations of Steller's eider and probably also king eider.Several of the seabird populations in the Barents Sea region are of international importance. The most numerous 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 - in Svalbard and Franz Josef Land.

Among more than 30 seabird species breeding and wintering in the Barents Sea region, there are seven Red-listed species including two from the global list (IUCN, 2008), six from Norwegian Red List and three from the Red Data Book of the Russian Federation. Besides, there are four more species listed in the Annex to the Red Data Book of the Russian Federation that are of concern. The only species listed in all three categories of the Russian Red lists is the ivory gull . Major threats likely limiting population development of the Red-listed seabird species are: (i) - fisheries (competition for the resources and by-catch in gill-nets); (ii) - environmental deterioration (pollution, habitat destruction and disturbance); (iii) - climate change (Anker-Nilssen et al., 2000). Fishery 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 might become more important in the future (currently it is considering important for the ivory gull only). Since seabirds are migratory species, causes of their unfavourable population status might lie beyond the Barents Sea region boundaries.

The Steller's eider *Polysticta stelleri* is classified as globally threatened and is thus a species of global conservation concern (Tucker and Heath, 1994). It is listed as vulnerable by IUCN (2008). Large numbers of this rare and declining seaduck winters along the coast of Finnmark and the Kola Peninsula in significant numbers (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 the Norwegian wintering areas (Systad unpublished data). The status for the species is uncertain, and needs to be followed closely.

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Norwegian responsibility species, with a minimum of 25% of the European population breeding or wintering in Norway, includes three breeding populations of seabirds (great black-backed gull *Larus marinus*, black-legged kittiwake and atlantic puffin), and eight wintering species/populations (great northern diver, great cormorant *Phalacrocorax carbo*, European shag *P. aristotilis*, Steller's eider, king eider, red-breasted merganser *Mergus serrator*. All ten species/populations are within the Barents Sea region all year round or in one or more seasons. Russian responsibility species, with a minimum of 25% of the European population breeding or wintering in the Russian part of the Barents Sea, includes breeding populations of ivory gull and king eider, and wintering populations of Steller's eider and probably also king eider.

4.3.9 Introduced species

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

In recent decades, some species that may be considered to be both - introduced and invasive, have appeared in the Barents Sea. There are currently 15 of them.

These organisms entered the Barents Sea both in a natural way - through the expansion of habitat due to global warming, and as a result of human activities, related to the intentional or accidental introduction of alien organisms.

At present, studies related to the invasive species are mainly focused on two kinds of crabs: Red king crab (*Paralithodes camtschaticus*) and Snow crab (*Chionoecetes opilio*), that are of economic importance. Scientific information regarding other invasive species is fragmentary and requires further research.

Below is an annotated list of introduced species of the Barents Sea, with more details about the two species of crabs:

- *Codium fragile ssp fragile*. 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* 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* 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* 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.* 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.

4.3.9.1 Red king crab (Paralithodes camtschaticus)

Cooperation in stock management

JRNFC). At the first stage of the work (1993-2001), the main purpose was to prepare a common strategy in the management of the stock which was considered to be a joined stock. It was proposed that by dividing the commercial stock into self-reproducing subpopulations, it was reasonable to have a separate management, i.e. to establish a TAC for each stock unit. Based on a long-term research, the JRNFC approved a proposed management regime and measures for the king crab management in 2000 and 2001 respectively.

The main principles of the strategy were the rule of three “S” (Sex, Size, Season), i.e. only males with a minimum legal size could be harvested at a certain level of exploitation using only traps in autumn-winter.

However, despite the reached agreements to establish common principles of management of a new biological resource, in 2005-2007, both parties agreed to manage the crab stock separately within their respective economical zone, and only to inform each other about the national measures taken. In Norway, the main research goals have been on revealing the effects of the red king crab on the ecosystem and prevention of its further distribution in the Norwegian waters. In Russia, however, the main focus is on a rational harvest of the stock. In Norway, the crab fishery is subjected to two different regimes. In a limited commercial area east of 26 ^{o} E 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 the principles agreed upon with the Norwegian party. Thus, the new stock of the red king crab is subjected to three different management principles: in the Russian waters they are based on elements of the precautionary approach; in the open Norwegian waters and to the west of the North Cape, there is an open fishery to prevent spreading, and in the fjords of eastern Finnmark, the fishery aimed to sustaining a low level of the stock.

The effect of red king crab on the Barents Sea ecosystem

The study of impacts of the red king crab and the Barents Sea fauna were significant themes in two three-year Joint Russian-Norwegian research programs on this species during 2002-2004 and 2005-2007. The consequences of the red king crab were studied both at a crab population and a benthic community levels. Main subjects were effects of the crabs feeding activity on benthos and the relations between the crab and other commercial species with emphasis on the crab being a predator and a competitor for prey organisms.

The Motovsky Bay in the southern Barents Sea was the main area for these studies. This area was chosen since it was the area where the crab has been abundant since the introduction to the Barents Sea. In addition, there are several published results from earlier investigations on the benthos in this bay, during 1931-1932 and 1996 - 2003. The king crab has inhabited these areas for more than four decades and is probably most adapted to its new environment here. The benthos community in this area is dominated by the sedentary polychaete *Maldane sarsi*. Investigations showed that the red king crab has not had any significant impact on the indices of abundance and the diversity of the benthic community in the deep-water part 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 northeastern part of the bay.

In conclusion, it seems that the observed changes in benthic communities in this area were more likely induced 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 at all in 2008 and very few specimens of the sea urchin *Strongylocentrotus droebachiensis* were found, which were common in 1994. 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 was abundant at the shallowest station (10 m 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, E. and Sundet, J.H., 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 t of capelin eggs were eaten by crabs in the 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 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 tons. 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 significantly on the spawning stock of capelin.

Long term studies have shown that the main food items of the crab (echinoderms, molluscs, worms) in the Barents Sea are also major prey species for the haddock. Therefore, any food competition between the king crab and haddock should result in lower frequency of occurrence in haddock stomachs. A comparative analysis of haddock stomach content in the period of low abundance of the red king crab (1971-1977) and when its abundance increased (1995-2002) was made. The analysis made did not reveal indications of any food competition between these two species in the Russian part of the Barents Sea.

4.3.9.2 Snow crab (Chionoecetes opilio)

After the first snow crab had been found on the Goose Bank in 1996 the number of reports on the snow crab by-catches in bottom trawl fishery has gradually increased (Pavlov, 2002). Since 2003 the snow crab has been observed in stomachs of cod, haddock, catfishes and thorny skate and thereby became a new food item for bottom fishes in the Barents Sea. In 2005, a snow crab was, for the first time, found during the ecosystem survey. In 2005-2008, the number of trawl stations where this species occurred and the number of individuals per station, increased. During that period, the crab was found in bottom trawl catches in most of the eastern Barents Sea concentrated mainly in the areas adjacent to the Goose Bank and the southern extremity of the Novaya Zemlya.

In 2007-2008, directed trawl surveys for the snow crab was conducted for the first time. At the Goose Bank and adjacent areas in the eastern Barents Sea were surveyed. During the surveys, highest number of snow crabs was 95 specimens per haul/hour. Males predominated (84%) in the catches and the greatest density of crabs (145-320 ind./km^2) was registered to the south of the Goose Bank.

The results indicate that the snow crab has adapted to the Barents Sea and it is assumed that the abundance of this crab will grow in the eastern Barents Sea in the nearest future. Due to this, it is expedient to monitor the distribution and abundance of the crab regularly, and to estimate any impact on the native ecosystem.

4.4 Human activities /impact

This chapter deals with the current status of human activities and the impact they are currently having on the Barents Sea ecosystem as revealed by the most recent data. General background information on human activities and their impact is given in chapters 2.5 and 2.6.3, respectively.

4.4.1 Fisheries

K. V. Drevetnyak (PINRO), C. Kvamme (IMR), K. Nedreaas (IMR), K. M. Sokolov (PINRO), and S. Aanes (IMR)

4.4.1.1 Fishes

Fisheries are meant to influence the ecosystem by removing sustainable quantities of fish as food for humans. The fishery is, however, not considered sustainable if it impairs the recruitment of the fish stocks. Single species management often focuses on measuring the status of the fishery in relation to benchmarks called biological reference points (BRPs). BRPs for single species management are usually defined in terms of fishing mortality rate (F) and total or spawning stock biomass (TSB or SSB) and in terms of target and limit reference points. 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 state of the fishery and suggest management actions.

The limit reference point for fishing mortality, F_{lim}, will eventually bring the spawning stock down to B_{lim}, below which the recruitment will be impaired. F_{lim} may hence be used as an indicator for not sustainable exploitation and negative influence on the stock and the ecosystem. This may, however, not be considered as sufficient protection. Smaller and younger adults resulting from high fishing pressure have a lower reproductive potential than adults of a wider range of sizes and ages. The harvest rate and fishing pattern should hence fit with these biological requirements.

Northeast Arctic cod, haddock and saithe

Figure 4.4.1 shows the annual fishing mortalities of the Northeast Arctic cod, haddock and saithe stocks relative to the critical exploitation level F_{lim}. Since 1985 the exploitation rate has in some periods been critically high, especially for cod. This seems to have improved in recent years (because of the harvest control rule and better control and enforcement), and although the exploitation rate may have been too high to fully utilize the production potential in the stocks, it may be concluded that the exploitation of these three stocks since 2000 have been sustainable and has not influenced the ecosystem negatively by impairing the recruitment.

Golden redfish (Sebastes marinus) and Greenland halibut

For golden redfish and Greenland halibut no limit reference points have been suggested or adopted. ICES has, however, in earlier assessment working groups for several stocks

estimated the exploitation rate F_{med} which is the fishing mortality that balance the number of fish caught and the number of fish recruiting to the fishable stock. For the Greenland halibut stock F_{med} was estimated to 0.14 y^{-1}. It should be noted that the time series of Greenland halibut fishing mortalities are considered imprecise due to errors in former age readings.
Experience from other *Sebastes* stocks, e.g, in the Pacific and in the Irminger Sea, suggests that annual harvest rates of such slow growing and long-lived species should not exceed 5% if the stock is recruiting normal. This corresponds to a fishing mortality of 0.05 y^{-1}, and this level is shown as a reference for the maximum sustainable exploitation rate for golden redfish in Figure 4.4.2. At a time when this stock is not recruiting normal even an annual exploitation rate of 5% may be too high. It can thus be concluded that the current fishery of golden redfish is too intensive and may have a negative influence on the ecosystem and the stock itself. For Greenland halibut, after many years of overexploitation of the stock the current exploitation seems, with some reservations due to an imprecise assessment, to be sustainable and hence not influencing the ecosystem negatively.

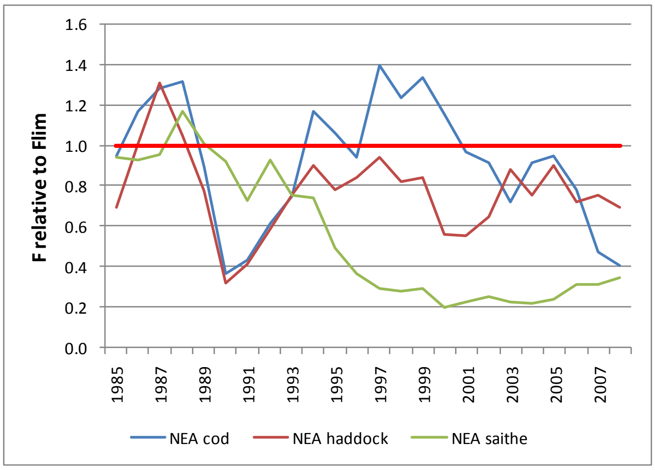

Figure 4.4.1. Annual fishing mortalities of the Northeast Arctic cod, haddock and saithe stocks relative to the critical levels above which the fishing mortality will impair the recruitment (ICES 2009).

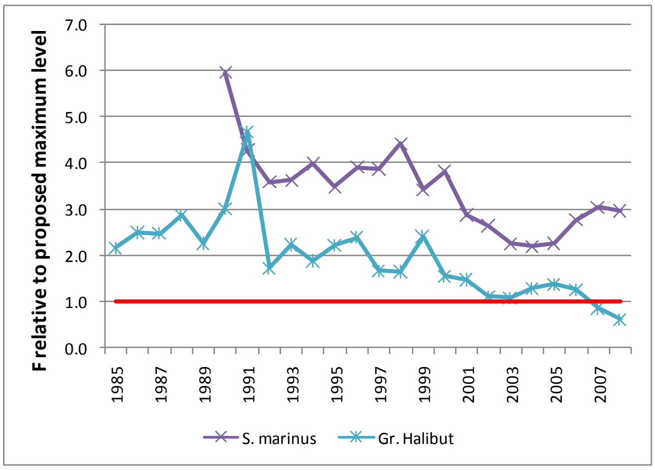

Figure 4.4.2. Annual fishing mortalities of Golden redfish (Sebastes marinus) and Greenland halibut (Reinhardtius hippoglossoides) relative to the proposed maximum levels above which the fishing mortality over time most probably will impair the recruitment (ICES 2009).

Beaked redfish (Sebastes mentella)
There exist at present no analytical assessment or reference points for this stock. From scientific surveys in the Barents Sea and Svalbard areas (Spitsbergen archipelago), it is confirmed that the stock is historically low taking all age groups into consideration, and this situation is expected to remain for a considerable period irrespective of current management

actions. A directed pelagic fishery for *S. mentella* in international waters (outside EEZ) of the Norwegian Sea has developed since 2004. In 2009 this fishery is limited by a total quota of 10 500 tonnes. Results from pelagic surveys conducted since 2007 indicate a significant mature biomass of beaked redfish in the Norwegian Sea, but the estimate is uncertain. Since the stock produced very few recruits from 1991 to 2005, the recruitment to the fishable and mature stock in the next 12-15 years will be low. ICES hence states that it is necessary to prevent the stock from declining further and to maintain measures to protect this stock from bycatch in other fisheries. ICES recommends that there should be no directed trawl fishery on *Sebastes mentella* in Subareas I and II in 2010. Some signs of improved recruitment in the Barents Sea and Svalbard areas are found. These recruits need protection and careful monitoring.

Larvae and juveniles of all groundfish species are important predators on zooplankton. It is hence important for a sound ecosystem that there are sufficient plankton eaters present to utilize the plankton production and convert this into production of fish, both as food for humans, but also as food for other fishes and sea mammals that depend on fish prey. It is therefore not sufficient to manage the fish stocks to the extent that the recruitment is not impaired as seen from a single species point of view, but rather to maximize the larvae production as a valuable food contribution to the ecosystem as a whole.

Capelin

The fishery for capelin is regulated by quotas set according to 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 approach to fisheries management. The fishery is restricted to the pre-spawning period and the exploitation level is regulated based on a model taking natural mortality including predation from cod into consideration.

Polar cod

In recent years the fishery has been at a very low level compared to stock level, implying a low exploitation level which will not influence the stock.

Other fish species

Information about the species composition in the Norwegian fisheries north of 67°N is available from the Norwegian Reference fleet (NRF), i.e., 17 high-seas and 10 coastal fishing vessels contracted by the Institute of Marine Research. Table 4.4.1 shows the species composition in the trawl and longline catches by the NRF during autumn 2008. Such data are now routinely being collected from these vessels’ fishery every day. What impact the fishery may have on all these species and the ecosystem as a whole will be a subject for further research.

Table 4.4.1. Species composition, incl. non-commercial species, in bottom trawl (left) and longline (right) catches done by the Norwegian Reference Fleet during autumn 2008.

Norwegian longline		**Norwegian bottom trawl**	
Species	**W %**	**Species**	**W %**
Cod	41,3	Cod	46,4
Haddock	37,3	Haddock	23,3
Wolffish - Anarhichas dentkulatus	6,6	Saithe	17,8
Greenland halibut	3,8	Greenland halibut	7,3
Wolffish - Anarhichas minor	2,7	Golden redfish	1,5
Tusk	2,5	Wolffish - Anarhichas lupus	1,5
Golden redfish	1,7	Beaked redfish	0,8
Wolffish - Anarhichas lupus	1,4	Wolffish - Anarhichas minor	0,4
Amblyraja radiata	1,3	Wolffish - Anarhichas dentkulatus	0,3
Ling	0,4	Atlantic halibut	0,2
Saithe	0,2	Amblyraja radiata	0,1
Long rough dab	0,2	Ling	0,1
Atlantic halibut	0,1	Tusk	0,1
Roughhead grenadier	0,1	Lumpsucker	0,1
Chimaera monstrosa	0,1	Chimaera monstrosa	+
Anglerfish	+	Anglerfish	+
Beaked redfish	+	Long rough dab	+
Greater forkbeard	+	Raja clavata	+
Dogfish	+	Greater forkbeard	+
Whiting	+	Roundnose grenadier	+
Shagreen ray	+	Blue whiting	+
Galeus melastomus	+	Argentina silus	+
Velvet belly lantern shark	+	rajella fyllae	+
Pollock	+	Smaller redfish	+
Rajella Fyllae	+	Bathyraja spinicauda	+
Redfish unspec.	+	Common sole	+
Spinetail ray	+	Hake	+
Eelpout	+	Mackerel	+
Plaice	+	Norway pout	+
Mora	+	Herring	+
Flounder	+		
Arctic skate	+		
Blue ling	+		
Smaller redfish	+		
Grey gunard	+		

Information about the total species composition in the Russian bottom trawl fisheries in Barents Sea and adjacent waters is available from the 30 high-seas fishing vessels with sea-observer of PINRO (total 3063 day at sea in 2008), and which is considered representative for the whole fleet (Table 4.4.2). The data were collected all year round and in all fishing areas of the Russian bottom trawl fleet (Figure 4.4.3).

Table 4.4.2. Species composition, incl. non-commercial species, in bottom trawl catches done by the Russian trawlers with sea-observer of PINRO during 2008.

Russian bottom trawl	
Species	**W %**
Cod	49,0
Greenland halibut	19,0
Haddock	17,0
Capelin	8,0
Plaice	4,0
Wolffish - Anarhichas minor	0,9
Beaked redfish	0,7
Wolffish - Anarhichas dentkulatus	0,7
Golden redfish	0,3
Long rough dab	0,2
Saithe	0,1
Polar cod	+
Lumpsucker	+
European smelt - Osmerus eperlanus	+
Atlantic navaga - Eleginus navaga	+
Common dab	+
Polar flounder	+
Wolffish - Anarhichas lupus	+
Herring	+

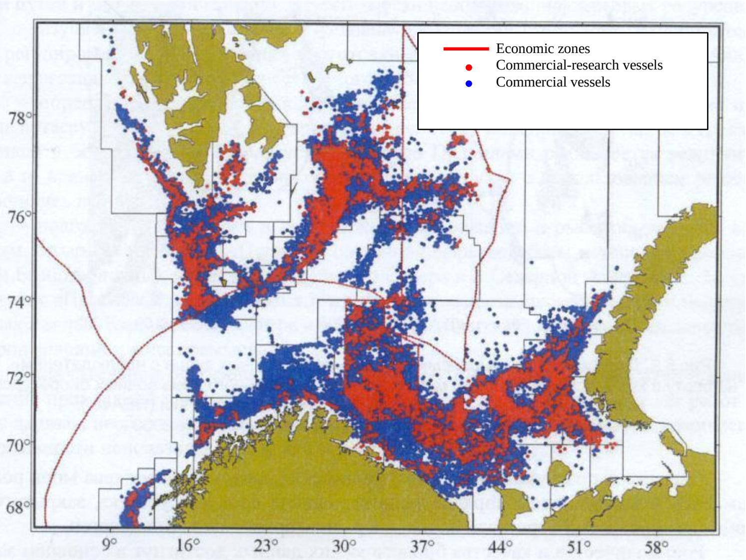

Figure 4.4.3. Location of Russian fishing and research-fishing vessels with observers on board in the Barents Sea and adjacent waters in 2008.

4.4.1.2 Discards

The level of discarding in the fisheries is not known, and no discards are accounted for in the assessments. Discarding is known to be a (varying) problem, e.g., in the haddock fisheries where discards is highly related to the abundance of haddock close to, but below the minimum legal catch size. Dingsør (2001) estimated discards in the commercial trawl fishery for Northeast Arctic cod during 1946-1998 and the effects on the assessment, and Sokolov (2004) estimated cod discard in the Russian bottom trawl fishery in the Barents Sea in 1983-2002. The lack of discard estimates leads to less precise and accurate stock assessments, and the influence of the fishery on the ecosystem is hence not fully understood.

Registration of redfish (dominated by *S. mentella*) taken as bycatch and discarded in the Norwegian shrimp fishery in the Barents Sea since 1984 show that shrimp trawlers removed significant numbers of juvenile redfish during the beginning of the 1980's. peaking in 1985 when by-catches amounted to about 200 million individuals. As sorting grid became mandatory in 1993, by-catches of redfish reduced drastically during the 1990's. The results also show that closure of areas is necessary to protect the smallest redfish juveniles since these are not sufficiently protected by the sorting grid. The by-catch and discard of cod mainly consists of 1- and 2-year-olds, but is generally small compared to other reported sources of mortality like catches, discards in the groundfish fisheries and cannibalism.

Noticeable discards of cod occurred in 1985, 1992 and 1998. The highest recorded numbers of cod was in 1985 (92 millions). The cod by-catches have declined in recent years (< 3 millions). Discards of haddock and Greenland halibut in the Barents Sea shrimp fishery have been estimated for the period 2000-2005, and show the highest discard in 2002 and 2000 for haddock (9.2 millions) and Greenland halibut (13.2 millions), respectively. For both species the discard in the shrimp fisheries has been low in the most recent years.

4.4.1.3 Shellfish

Northern shrimp

The 2008 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. The advised TAC (quota) for 2009 is 50,000 tonnes.

Red king crab

Outside 12 nautical miles in the Norwegian Economic Zone (except the Grey Zone), and inside 12 nautical miles west of 26°E, the goal is to eradicate the red king crab. Inside 12 nautical miles east of 26°E in Norwegian waters, and in the Russian part of the Barents Sea, the goal is to harvest the king crab sustainable. The harvest rate of the red king crab within the regulated fishing areas in both Norwegian and Russian waters is high, and it remains to see whether it is sustainable. Especially in Norwegian waters where both male and female crabs are caught, and there are no seasonal restrictions for catch. This management contradicts the basis for the management regimes applied in the Bering Sea (Alaska) and in the Russian part of the Barents Sea.

4.4.1.4 Marine mammals

Minke whale

The management of this species is based on the Revised Management Procedure (RMP) developed by the Scientific Committee of the International Whaling Commission. The inputs to this procedure are catch statistics and absolute abundance estimates. The present quotas are based on abundance estimates calculated from surveys conducted in 1989, 1995, 1996–2001 and 2002–2007. The most recent estimates (2002–2007) are 78,500 minke whales for the Northeastern stock, and for the Jan Mayen area, which is also exploited by Norwegian whalers, 24,900 animals. The present (2009) quota of 885 animals is considered precautious, conservative and protective for the minke whale population in the Northeast Atlantic. At present only Norway utilizes this quota.

Harp seals

The Northeast Atlantic stocks of harp seals are assessed every second year by the Joint ICES/NAFO Working Group on Harp and Hooded Seals. The assessments are based on modelling, which provides ICES with sufficient information to give advice on both status and catch potential of the stocks. The current adult population is close to the lowest observed in the historical time series. ICES considers the catch model for the White Sea/Barents Sea harp seal population to be unreliable for estimating the impact of future catches. However, the Potential Biological Removal (PBR) approach was used to estimate a catch of 21 881 animals, which is generally regarded as sustainable. The catches in recent years have been lower than the quotas.

4.4.1.5 Important indirect effects of fisheries on the ecosystem

In order to conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. In general, the response of benthic organisms to disturbance differs with substrate, depth, gear, and type of organism (Collie et al. 2000). Seabed characteristics from the Barents Sea are only scarcely known (Klages et al. 2004) and the lack of high-resolution (±100 m) maps of benthic habitats and biota is currently the most serious impediment to effective protection of vulnerable habitats from fishing activities (Hall 1999). An assessment of fishing intensity on fine spatial scales is critically important in evaluating the overall impact of fishing gear on different habitats and may be achieved, for example, by satellite tracking of fishing vessels (Jennings et al. 2000).The challenge for management is to determine levels of fishing that are sustainable and not degradable for benthic habitats in the long run.

The qualitative effects of trawling have been studied to some degree. The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. Barents Sea hard bottom substrata, with associated attached large epifauna should therefore be identified.

Effects on soft bottom have been less studied, and consequently there are large uncertainties associated with what any effects of fisheries on these habitats might be. 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 the benthic assemblage mainly through resuspension of surface sediment and through relocation of shallow burrowing infaunal species to the surface of the seafloor.

Work is currently going on in the Arctic, jointly between Norway and Russia, exploring the possibility of using pelagic trawls when targeting demersal fish. The purpose is to avoid impact on bottom fauna and to reduce the mixture of other species. It will be mandatory to use sorting grids to avoid catches of undersized fish.

Lost gears such as gillnets may continue to fish 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 in depths shallower than 200 m is usually not a significant problem because lost, discarded, and abandoned nets have a limited fishing life owing to their high rate of biofouling and, in some areas, their tangling by tidal scouring. Investigations made by the Norwegian Institute of Marine Research of Bergen in 1999 and 2000 showed that the amount of gillnets lost increases with depth and out of all the Norwegian gillnet fisheries, the Greenland halibut fishery is the metier where most nets are lost. The effect of ghost fishing in deeper water, e.g. for Greenland halibut, may be greater since such nets may continue to "fish" for periods of at least 2–3 years, and perhaps even longer (D. M. Furevik and J. E. Fosseidengen, unpublished data), largely as a result of lesser rates of biofouling and tidal scouring in deep water. The Norwegian Directorate of Fisheries has organised retrieval surveys annually since 1980. All together 10 784 gill nets of 30 metres standard length (approximately 320 km) have been removed from Norwegian fishing grounds during the period from 1983 to 2003.

Other types of fishery-induced mortality include burst net, and mortality caused by contact with active fishing gear, such as escape mortality (Suuronen 2005; Broadhurst et al. 2006; Ingólfsson et al. 2007). Some small-scale effects are demonstrated, but the population effect is not known.

The harbour porpoise is common in the Barents Sea region south of the polar front and is most abundant in coastal waters. The harbour porpoise is subject to by-catches in gillnet fisheries (Bjørge and Kovacs 2005). In 2004 Norway initiated a monitoring program on by-catches of marine mammals in fisheries.

Fisheries impact seabird populations in two different ways: 1) Directly through by-catch of seabirds in fishing equipment and 2) Indirectly through competition with fisheries for the same food sources.

Documentation of the scale of by-catch of seabirds in the Barents Sea is fragmentary. Special incidents like the by-catch of large numbers of guillemots during spring cod fisheries in Norwegian areas have been documented (Strann et al. 1991). Gillnet fishing affects primarily coastal and pelagic diving seabirds, while the surface-feeding species will be most affected by long-line fishing (Furness 2003). The population impact of direct mortality through by-catch will vary with the time of year, the status of the affected population, and the sex and age structure of the birds killed. Even a numerically low by-catch may be a threat to red-listed species such as Common guillemot, White-billed diver and Steller's eider.

Several bird scaring devices has been tested for long-lining, and a simple one, the bird-scaring line (Løkkeborg 2003), not only reduces significantly bird by-catch, but also increases fish catch, as bait loss is reduced. This way there is an economic incentive for the fishermen to use it, and where bird by-catch is a problem, the bird-scaring line is used without any forced regulation.

In 2009, the Norwegian Institute for Nature Research (NINA) and the Institute of Marine Research in Norway started a cooperation to develop methods for estimation of bird by-catch. Preliminary reports from observers at sea trained by the institutes show that most of the fisheries have a minor impact on bird mortality.

4.4.2 Pollution

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The Barents Sea environment is to a large extent a clean. Monitoring results indicate generally low levels of contaminants, with some exceptions. The levels of most heavy metals are low, with the exception of Ni and As in sediments. Levels of atmospheric input of heavy metals into the area are decreasing for some metals, but increasing for others. For most of the monitored substances in the Barents Sea the levels of contamination are well below the limit values for human consumption. The concentration of heavy metals and POPs is generally lower in the Arctic environment than in temperate regions but in the last few years there is a tendency for an increase in concentration in air for some POPs like HCB and PAH. Persistent organic pollutants (POPs) that accumulate in organisms at the top of the food chain are of special concern. Another matter of concern is distribution and contents of radioactive substances in the marine environment which may pose major risks to the whole ecosystem.

This chapter represent some of the monitoring results from the area.

The status of contaminants in the Barents Sea is based on current knowledge. There is a lack of long time trends for many of the components (see Table 3.3.3) and there are also areas were knowledge is limited.

4.4.2.1 Current status and trend for POPs

Air

Atmospheric transport is believed to be the most important transport route for volatile and semi-volatile persistent pollutants into the Arctic (AMAP 2004). In the Barents region, data on atmospheric pollution from the Zeppelin mountain atmospheric research station (Ny-Ålesund, Svalbard, Norway) has shown a significant decrease in pollutants during the past decade (Figure 4.4.4).

However during the past 4 years, levels of hexachlorobenzene (HCB) at the Zeppelin station have been increasing again (Hung et al. 2009, Figure 4.4.5). This substance was formerly used as a fungicide, but is today released into the environment as by-product of various industrial chemical processes. Increase is also found in levels of ΣPAH in 2007 (Figure 4.4.6).

This feature is only observed at the Zeppelin station. No similar trends are reported from other Arctic atmospheric monitoring sites (e.g. Alert, Storhofdi, Pallas). The increasing concentration levels may be explained by increased evaporation of previously deposited HCB from the open ocean along the western coast of Spitsbergen (Svalbard, Norway) which has been ice-free during the past four years, including the winter seasons (2005-2008). Although there has been a dramatic decrease in sea ice also in other parts of the Arctic, a permanent all year round ice-free situation at 80º N latitude is exceptional to-date. Therefore, this signature could be interpreted as a possible direct signature of regional climate change on the POP distribution in the environment around the Barents Sea. Similar trends were seen in Zeppelin air samples for middle chlorinated polychlorinated biphenyls (penta- to hexa-chlorinated CBs) and dichlorodiphenyltrichloroethane derivatives (DDT). Regarding DDT, the re-introductions as insecticide in the tropic regions for Malaria control purposes and the related increased frequency of transport episodes from primary sources (direct application in agriculture) in low latitudinal source regions may also contribute to the currently increasing levels in the North.

The Barents Sea also receives contaminant loads associated to boreal forests from North Eastern Russia and North America. In spring (early May) of 2006, biomass burning emissions from agricultural fires in Eastern Europe were transported to Svalbard and the Zeppelin station and record-high levels of many air pollutants, including PCB, were recorded (Stohl et al., 2007). In July 2004, about 5.8 million hectare of boreal forest burned in North America and Northern Russia, emitting a pollution plume which reached the Zeppelin station after a travel time of 3-4 weeks (Stohl 2006). Again, PCB was elevated. The strong effects on observed concentrations far away from the sources suggest that biomass burning is an important source of PCBs for the atmosphere.

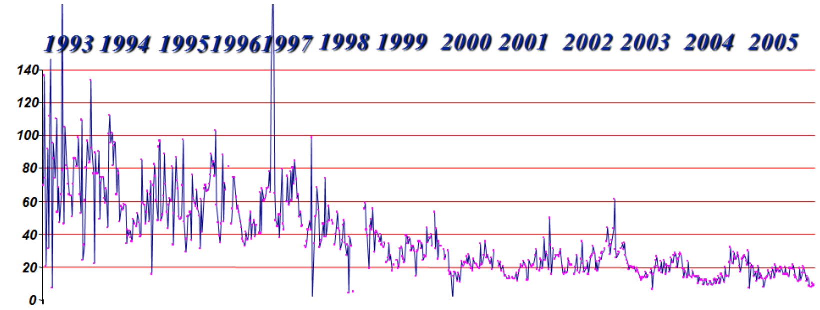


Figure 4.4.4 Concentration distribution (pg/m3) of □-HCH (hexachloro-cyclohexane) in weekly collected Zeppelin air samples from 1993 until 2005.

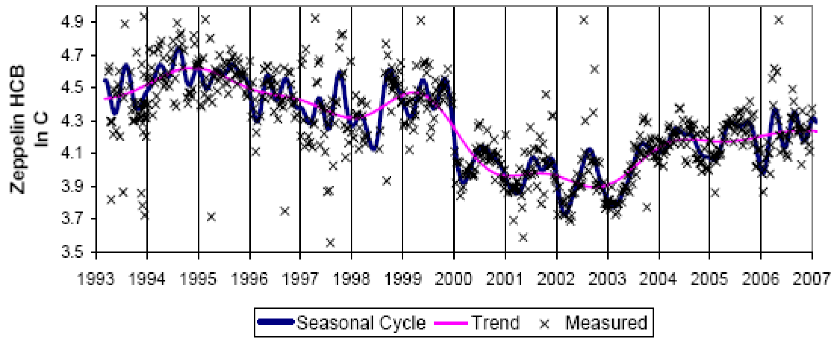


Figure 4.4.5. Temporal trend analysis for hexachlorobenzene (HCB) in Zeppelin air (1993 – 2007) using statistical digital filtration (DF). Please note: Concentration values are given in a logarithmic scale (ln).

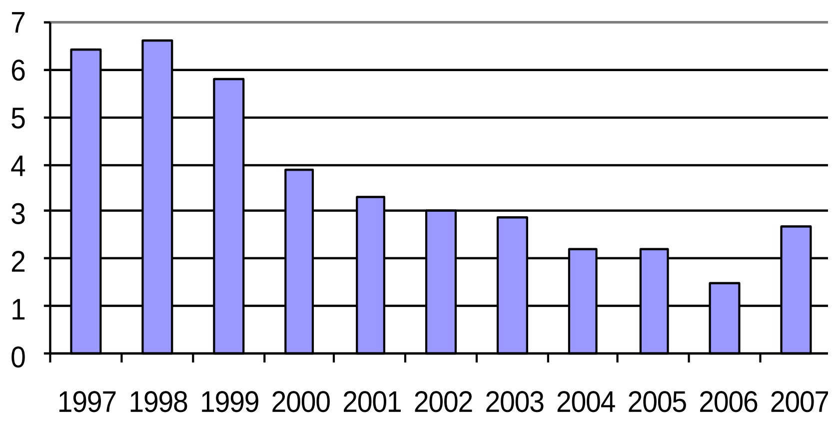


Figure 4.4.6.. Mean concentrations of ΣPAH in air at the Zeppelin station. Unit: Ng/m3. The figure shows that the yearly mean concentration of PAH has decreased from 1999 to 2006, but increased in 2007.

Sediments

Generally investigations of bottom sediments in the area reveal low levels of POPs. Data from ivestigations from 2005 shows that around the southern part of Svalbard concentrations of hexachlorcyclohexane (HCH) range from 0,27-2,26 ng/g dry weight. The increase in the relative concentration of the more stable isomer α- HCH in comparison with γ-HCH indicates a long lasting inflow of hexachlorocyclohexane into the marine environment. DDT was the predominant organochlorine pesticide in the examined bottom sediments. The concentration of DDT in bottom sediments from the studied areas varied from 0,36-1,79 ng/g dry weigh. According to the classification of contaminant levels in marine bottom sediments,(SFT 1997), investigated bottom sediments from the Barents Sea should be categorized as «moderately contaminated» by DDT. The contents of p,p-DDE isomer in bottom sediments exceeded the contents of p,p–DDT isomer at all investigated stations and indicates a prolonged transformation process of DDT into more stable metabolites. Levels of the DDT (metabolitt DDE) in sediments from the Norwegian coast of the Barents Sea are low, < 0,5 µg/kg dry weight, and corresponds to “background level”. Both data from the open sea areas and the Norwegian coast shows low levels of PCB and (0,7 -5,12 ng/ g dry weight).

Seafood

For most of the monitored substances in the Barents Sea the levels of contamination are well below the limit values for human consumption.

In cod liver the levels of dioxins and dioxin-like PCB measured by Norway in 2007 were relatively high. The levels were lower in 2008, but it is too early to say anything about trends. The levels of hazardous substances in blue mussels is generally low and time trend analysis reveals that the levels are decreasing. For the other species measured the levels of hazardous substances are low (Sunnanå et al 2009).

Data from the Russian side of the Barents Sea from 2005-2008 show that the combined concentrations of organochlorine pesticides (OCs) like HCHs, HCB, DDTs, chlordanes and toxaphene and polychlorinated biphenyls (PCBs) in muscle tissue of fish did not exceed the permitted levels approved by the "Russian sanitary code for raw food products and provisions". DDT (and its metabolites) was dominant; followed by the isomers of chlordane, HCH, and HCB. A few specific results are given in Table 4.4.3.

Table 4.4.3. Range in concentrations for selected organochlorine compounds in fish liver (µg/kg ww). (Data from IMR measurements 2000-2007).

Fish	HCHs	DDTs	PCBs	Toxaphene
Atlantic cod	1-5	130-160	120-180	90-110
Haddock	1-5	50-60	100-110	40-50

Residues of hexachlorocyclohexane (HCH), hexachlorobenzene (HCB), and chlordanes measured in fish muscles did not exceed 2 ng/g wet weight.. High concentrations of p,p-DDE compared to other isomers in fish muscles indicates that DDT transformation occurs over time.

Marine mammals and seabirds

POPs in animals 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 for effects on the hormone and immune system. PCB has been found in especially high concentrations (Gabrielsen 2007, Letcher et al. 2009). The trend across the Barents Sea shows increased levels of PCB from the western populations to the eastern populations, probably due to a larger long range transport of PCB substances from Europe to Svalbard and the Barents Sea area. The 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).

The level of hazardous substances in Brünnick's guillemot from the Kongsfjord and Bear Island is probably below the limit for effects on reproduction and/or survival. Analyzed samples are from 1993, 2002/2003 and 2007, and the general trend is a decrease in the level of most hazardous substances during this period (Bakke et. al. 2008).

4.4.2.2 Current status and trend for heavy metals

Air

Concentrations of elementary mercury (Hg) measured at the Zeppelin observatory is at the same level as the concentrations measured in the southern part of Norway. There are episodes during spring time where levels of elementary Hg in gaseous phase decreases (Figure 4.4.7). The reason for this decrease is that light from the polar sunrise starts a chemical prosess that transform Hg to more reactive components that becomes bioavailable. Such inter-annual trends have also been found at other sites in the Arctic (AMAP 2002). For other heavy metals measured in air, there are a decreasing trend for nickel (Ni) and lead (Pb) wheras other components show no or only minor changes in concentrations since 1994 (Aas et al. 2008). Reductions of Pb in the atmosphere are measured in the whole Arctic as a result of a ban on the use of leaded gasoline (AMAP 2004).

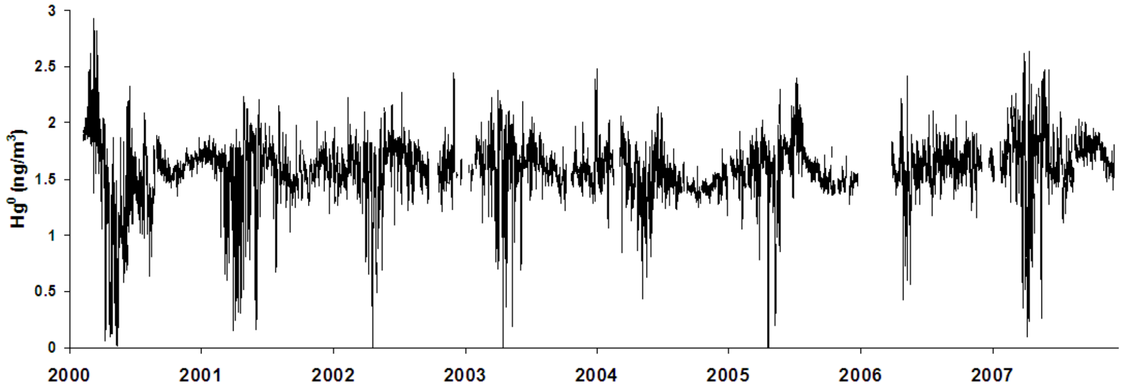


Figure 4.4.7. Fluctuations in concentrations of elementary Hg in gaseous phase at the Zeppelin observatory (Sunnanå et al. 2009).

Sediments

Recent sediment samples collected throughout the open ocean revealed levels within the limits of natural background levels of the heavy metals Zn, Cr, Co, Pb, Cd, and Hg (Knies et al., 2006, PINRO, Green et al. 2008).

The levels of Cu are also generally low. There are high natural background levels of Cu on the Kola peninsula and on the Novaja Zemlja (see Figure 4.4.8). The concentration of Cu increases in the northern direction from Varanday towards Novaja Zemlja. This can be due to a change in type of deposits, or run off from rivers and underground waters from Novaja Zemlja. The maximum concentration of Cu is found in silty-pelitic sediments in the Murmansk Trough (146 - 150 p.p.m), opposite Kola Bay. Apparently, these concentration are of natural character, connected with the clay structure in the bottom sediments, but run-off from the Kola bay is also a possible contributor.

The concentrations of Ni in bottom sediments exceed the natural background level (30 μg/g dw) at all the stations in the Kola Bay. The levels vary from 32 to 215 ppm, and exceeds the level of “considerable pollution” at several stations (SFT 1997). Nickel is the main metal in the metal-working industry at the Kola peninsula.

Arsenic (As) is present in high concentrations in the Barents Sea area. In the western part of the Barents Sea, As has been found in concentrations corresponding to Class III, marked pollution level, according to the classification guidance from the Norwegian Pollution Control Authority. In the eastern part of the Barents Sea the levels were in Class II (moderate pollution level). Maximum concentrations of As were found in bottom sediments in the area from the south of Novozemelsky to the Pechora sea. The average level of As concentration in sediments at the Kola polygon were 52,8 p.p.m for 2005-2008, lower than in the Pechora sea. The highest concentration of As was located opposite the mouth of the Kola Bay. The As concentration in silty-pelitic deposits in the open part of the Barents Sea was near 50-60 p.p.m.

Increase of concentration of As in clay deposits of the South Novozemelsky Through can be connected with its input as at the expense of a removal from Southern island of Novaja Zemlja and at the expense of infiltration of underground waters on faults. Occurrence of increasing concentrations of arsenic in nearmouth parts of Kola bay can be connected with its inflow from the Kola bay. Occurrence of local concentration of arsenic around the Shtokmanovsky deposit probably reflects inflow of gasfluids from bedrock.

Elevated barium (Ba) concentrations were encountered in the Håkon Mosby mud volcano area at the continental margin and near the Snøhvit gas/condensate field. The latter might be due to emissions of barite ($BaSO_4$) additive of drilling mud used during drilling operations in year 2000.

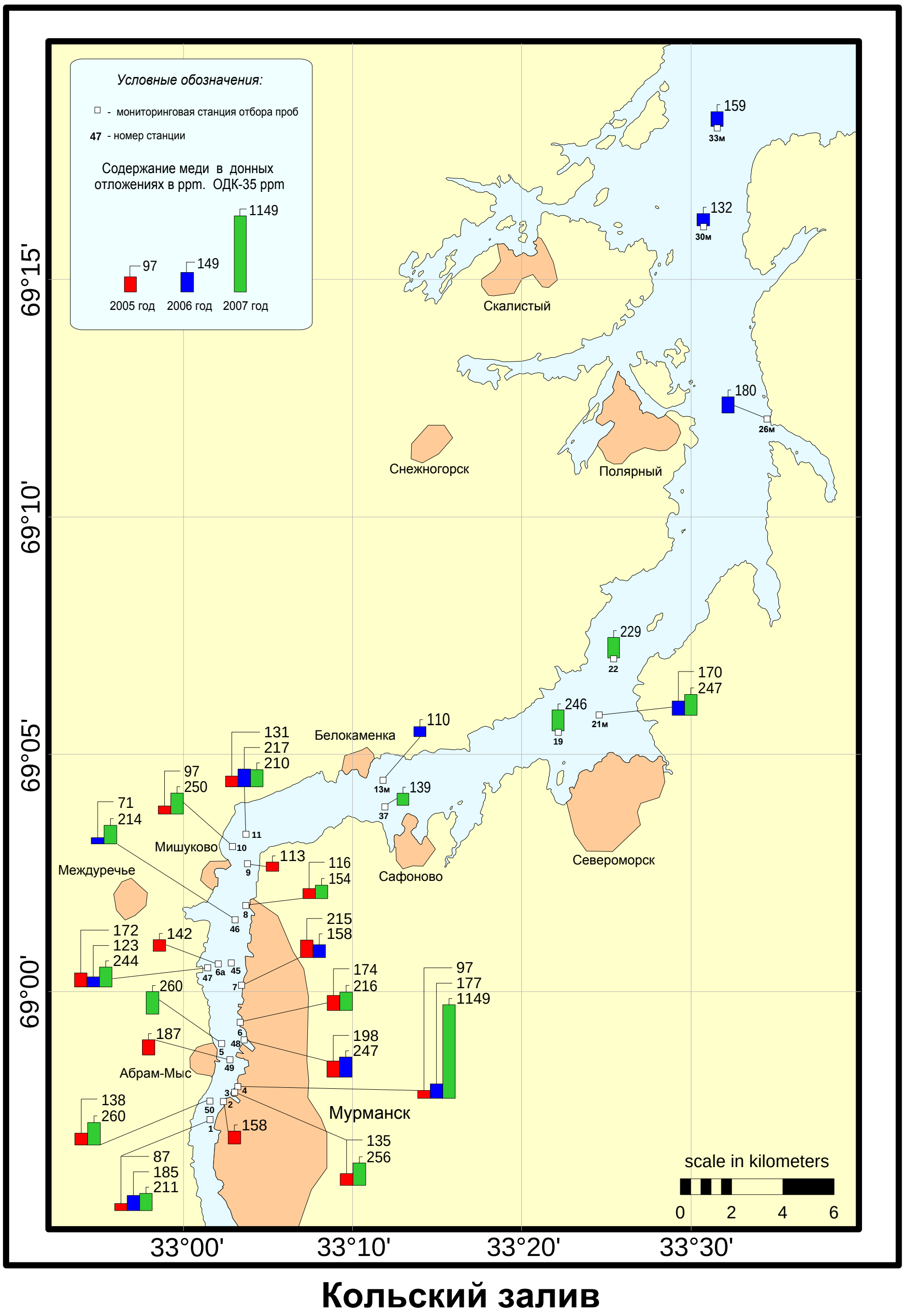


Figure 4.4.8. Distribution of Cu in bottom sediments in the Kola Bay in 2005-2007.

Seafood

Analysed fillets of cod from the Barents Sea had concentrations of Cd, Hg or Pb below EUs limits for food consumption (Sunnanå 2009). The values were at about the same level all three years from 2006-2008. Concentrations of Ca and Pb were higher in cod liver than in fillet, while the Hg consentrations were higher in cod filet (> 0,1 mg Hg/kg). There are no marginal value from EU metals in fish liver (Figure 4.4.9).

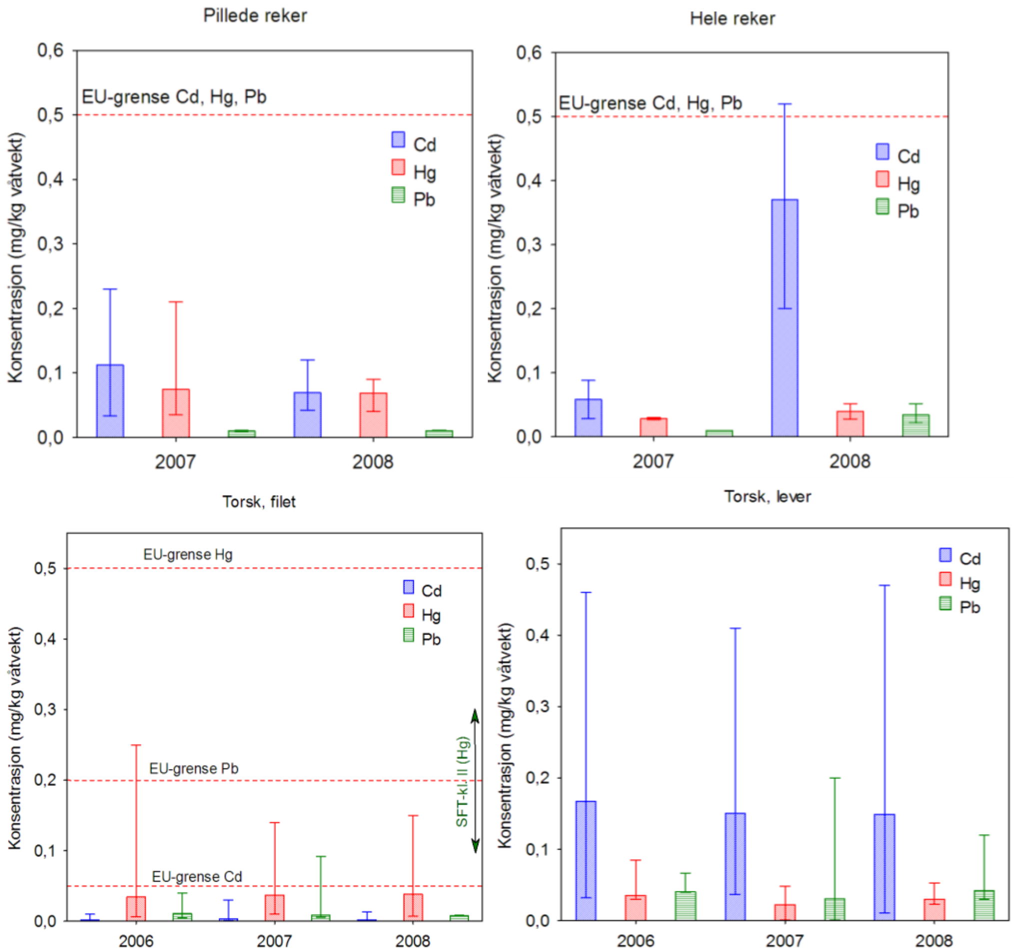


Figure 4.4.9. Levels of heavy metals in shrimp (picked and whole) and cod (fillet and liver) from samples taken from the open part of the Barents Sea (from Sunnanå et al. 2009).

Shrimp samples from 2007 and 2008 shows that the edible part of shrimps all had concentrations of metal below EUs limits for consumption. The levels of Cd were at the same level as analyses from 1995 and 2000. The concentrations of Cd and Pb were generally higher in whole shrimps than in analyses were only the edible part was included (see Sunnanå et al. 2009).

Low levels of heavy metals was also found in fish from the Russian side of the Barents Sea. Concentration of nickel, chromium, cobalt, lead, and cadmium in the muscles of all fish examined were below detectable limits. Concentrations of copper, zinc, and mercury varied within a very narrow range, and corresponded to natural background levels. Concentrations of cadmium in livers of all fish examined did not exceed the permissible level for consumption (0,7 µg/g ww). One exception was Atlantic wolfish where the concentration of cadmium in liver twice exceeded the standard. Concentrations of arsenic in individual samples from muscles of cod, long rough dab, wolffish, haddock and thorny skate exceeded the established standard of 5,0 µg/g ww.

4.4.2.3 Current status and trends for hydrocarbons

Oil contamination may be measured as total hydrocarbon content (THC) which includes both aliphatic and aromatic hydrocarbons. THC levels in sediments vary from below detection limit to below 20 µg/g dry weight throughout south-western and central parts of the Barents Sea, but are in the range of 50 to 70 µg/g dry weight in the areas closer to Svalbard (ibid.) in the North-Western Barents Sea.

In 2004, THC was measured in the offshore waters of the Norwegian part of the Barents Sea. The results were in the low µg/L range, reaching background levels at almost all the locations (ibid.) Near the offshore fields the levels of hydrocarbons are on or close to the background level. The exception in 2007 was a higher level of THC at three stations on the Snøhvit field.
Concentrations of aliphatic hydrocarbons (n-alkanes) found in the upper layer of the bottom sediments from Svalbard area varyed from 1 to 240 µg/g dry weight in 2005. Aliphatic hydrocarbons of biogenic origin (paraffins) dominated. The levels of n-alkanes (C_{10}-C_{32}) in upper layers of bottom sediments varied from 0,13 to 0,5 µg/g dw in western and central regions, and from 0,3 to 3,3 µg/g dw in the south-eastern region of the Barents Sea in 2006. The relation between the isoprenoides prystane (iC_{19}) and phytane (iC_{20}) can be used as a fractional conversion marker for the nature and condition of hydrocarbons in bottom sediments. The fact that hydrocarbons of biogenic origin dominate in aliphatic compounds is demonstrated by their ratio: prystane/phytane >2. There are no specific guidelines regarding n-alkanes concentrations in bottom sediments. Total aliphatic hydrocarbons levels in bottom sediments from the studied fishing areas in the Barents Sea were below the 340 µg/g dw background level, indicating anthropogenic influence. This level is representative for upper layers of bottom sediments on the western Arctic Shelf.

Sediments

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 20 PAHs throughout the Western Barents Sea, see Figure. 4.4.10 (Boitsov et al., 2007). The levels of PAH measured in sediments in the southern Barents Sea in 2006 and 2007 were very low, mostly < 300 µg/kg dry weight.

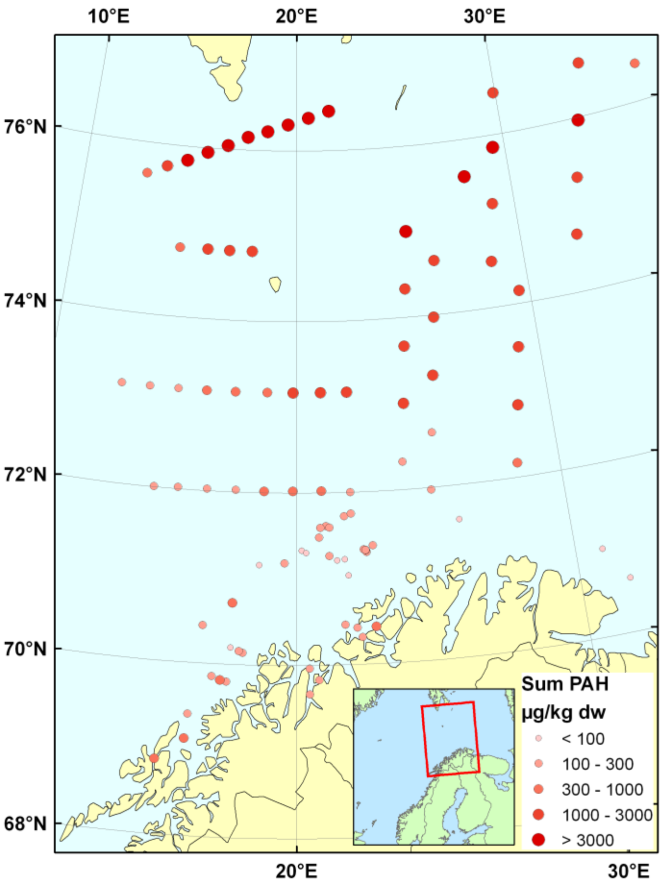


Figure 4.4.10. Sum PAH levels in Western Barents Sea sediments monitored by IMR.

Sediments in areas close to Svalbard have PAH levels at above 3000 µg/kg dry weight (ibid.), at least an order of magnitude greater than the levels measured elsewhere in the Barents Sea. Russian data from 2005 (Figure 4.4.11) reveal the same pattern. Maximum levels of polyaromatic hydrocarbons (PAH) (sum 16 compounds, EPA protocols 8310) were found in the bottom sediments in the fishery areas of the Western Spitsbergen and Spitsbergen bank.

Sum of carcinogenic PAH [benz(a)anhtracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benz(a)pyrene, indeno(1,2,3–cd)pyrene and dibenz(a,h)anthracene] varied from 29,3 ng/g to 340 ng/g dry weight, and constituted from 10 % to 40 % of the total PAH concentrations in the samples. Sum toxicity given as benz(a)pyrene equivalents for the investigated samples of bottom sediments varied from 7,50 ng/g to 76,8 ng/g dry weight. The results demonstrate the higher concentrations of PAH in bottom sediments from the coastal areas of Spitsbergen in comparison with other parts of the Barents Sea. The concentrations of PAH and benz(a)pyrene in bottom sediments in the investigated areas adjacent to Spitsbergen archipelago correspond to levels of "moderate contamination" (SFT 1997), although the levels are caused by natural processes.

A ratio of the sum of low molecular weight PAH concentrations to the sum of higher molecular weight PAH concentrations was used as criterion for PAH origin in Barents Sea bottom sediments. For the majority of stations, the ratio was below 1. This indicated that PAHs had formed as a result of fossil fuel burning. Quantitative measures indicated low concentrations of PAHs in bottom sediments within areas studied; this was particularly true for central and southwestern areas of the Barents Sea. In Russia, there were no specific classification guidelines for concentrations of contaminants in marine bottom sediments. According to Norwegian guidelines (SFT 1997), ΣPAH and benzo(a)pyrene concentrations in bottom sediments at most stations within the areas studied, did not exceed background levels: < 300 ng/g dw and < 10 ng/g dw. PAHs in the upper layers of the bottom sediments were mainly of pyrogenic origin.

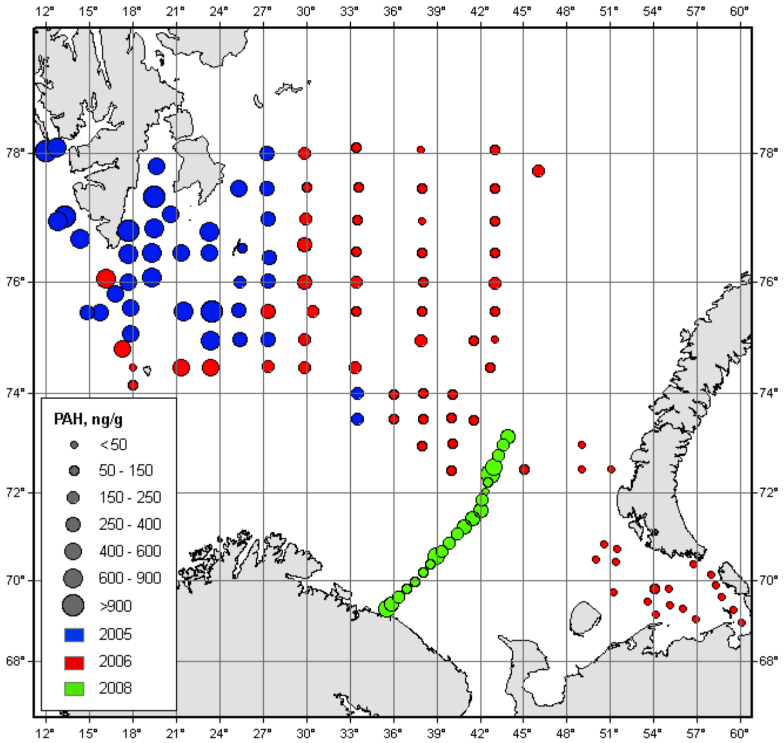


Figure 4.4.11. Sum PAH levels in Barents Sea sediments monitored by PINRO.

Despite an intensive technological burden, upper horizons of the geological environment (bottom sediment and quaternary holocene deposits) in the Russian part of the area are not disturbed. Contamination is absent over most of the area. The most contaminated areas are the Kola bay and some smaller bays where ships are stationed. There, the bottom sediments contain high amount of hydrocarbons. An example is the Kola bay where oil spills have lead to the formation of sea bottom deposits with a gross content of hydrocarbons, up to 5-10 mg/kg.

Although data on hydrochemistry of the bottom water suggests that the implemented clean-up measures have been effective, there is still a large reserve of hydrocarbons and other toxins in the bottom sediments. These toxins present a potential threat as a source for secondary contamination of the water column.

Seafood

The levels of PAHs in fish are routinely monitored in Norway to control the possible effects of the petroleum industry on the marine environment. The levels of PAHs measured in the muscle of cod and haddock from the Barents Sea in 2006 were very low (background), below

6 µg/kg wet weight for total PAH in cod muscle and below 4 µg/kg wet weight in haddock, indicating no contamination (Grøsvik et al., 2007).

This is consistent with Russian showing that the concentration of chlorinated hydrocarbons in fish muscle and liver tissue was well below allowable levels. The concentration of PAH was in most cases higher in the fish liver than in the muscles. This is natural as the liver is an accumulating organ. Among individual PAHs, phenanthrene was found at highest concentrations in fish muscle, naphthalene and benzo(g,h,i)perylene in liver. The concentrations of benz[a]pyrene in muscles of fish was below the detection limit of the applied method of analysis.

4.4.2.4 Current status and trends for radioactive substances

Overall the activity concentrations of such radionuclides as ^{99}Tc, ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, ^{241}Am, ^{226}Ra and ^{228}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.

The issue of present and potential radioactive contamination in the Barents Sea has received considerable attention in recent years. In the late 1980s several accidents and incidents involving nuclear-powered submarines demonstrated that the risk of releases of radionuclides into the Barents Sea should be considered more carefully.

In the early 1990s, information concerning the dumping of nuclear waste emerged through bilateral environmental cooperation between Norway and Russia (NRPA, 2008b). In the years that followed, concern grew regarding the safety of military and civil nuclear installations in the northwest of Russia. In addition, the long-range transport of radionuclides originating from nuclear weapons fallout, the Chernobyl accident (1986) and from spent nuclear fuel reprocessing are still the main contributors to anthropogenic radionuclides (^{99}Tc, ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, ^{241}Am) in the northern marine environment (Figure 4.4.12).

In 1994 and 1995, the discharge of ^{99}Tc from the reprocessing facility at Sellafield in the UK increased sharply as a result of commencement of operations at the Enhanced Actinide Removal Plant (EARP). There has been much public concern about the consequences of such kinds of releases, as radionuclides discharged to the Irish Sea are transported by ocean currents via the North Sea, into the Norwegian coastal current and to the Barents Sea. From 2004 the discharge of ^{99}Tc was substantially reduced, but it takes 3-4 years before it will be observable in Norwegian waters (NRPA, 2008b).

In 2005-2008 surface water, sediment samples and fish species from the Barents Sea were collected by the Norwegian Radiation Protection Authority (NRPA) and the Institute of Marine Research (IMR) to be analyzed for anthropogenic and naturally-occurring radionuclides (NRPA, 2007c and 2008b).

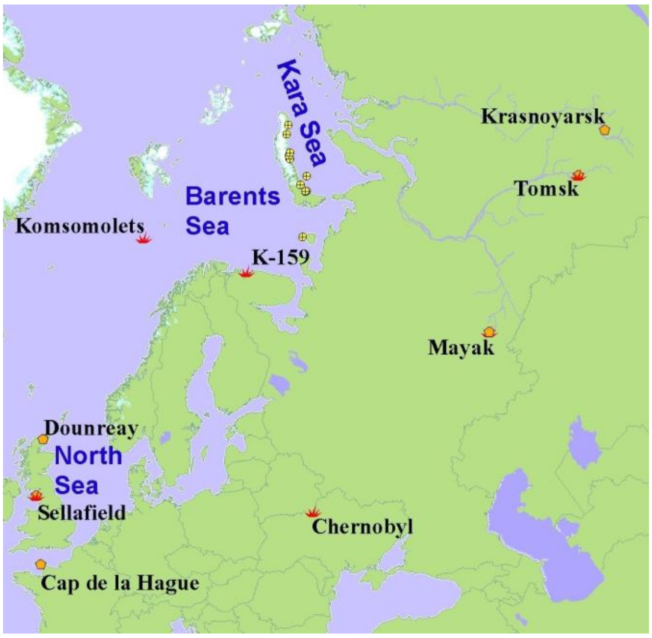


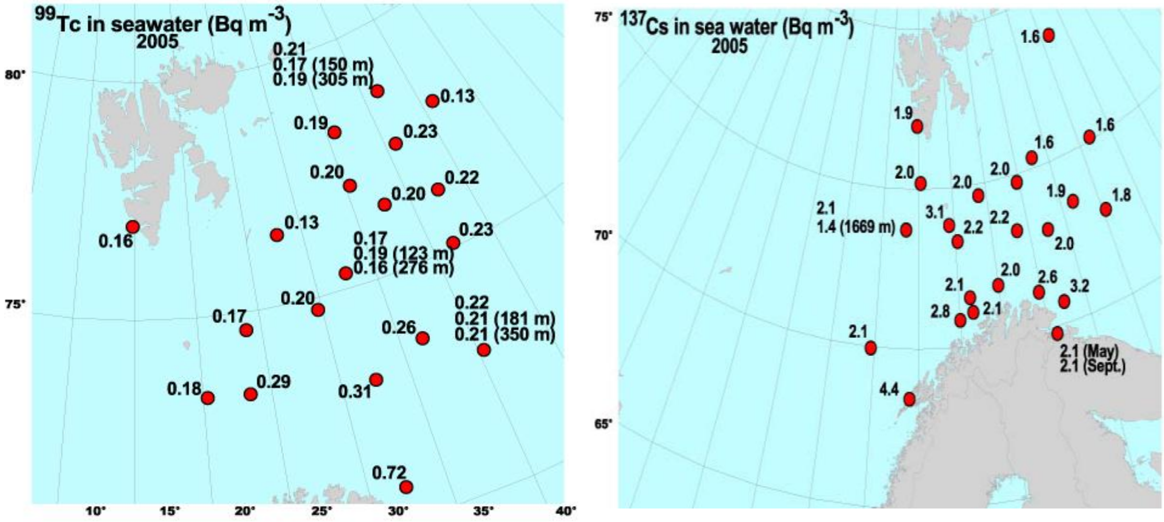
Figure 4.4.12. Sources of radionuclides in the northern marine environment: Chernobyl in the Ukraine, the reprocessing plants at Sellafield, Cap de la Hague and Dounreay, the dumping sites for nuclear waste in the Kara Sea, the sites of the sunken submarines Komsomolets and K-159 and the Russian nuclear installations (Mayak, Tomsk and Krasnoyarsk) releasing radionuclides to the Russian rivers Ob and Yenisey (NRPA, 2007).

Sediments and seawater

During 2005, ^{99}Tc activity concentrations in seawater water from the Barents Sea ranged from 0.13 to 0.72 Bq m^{-3} (Figure 4.4.13),), whereas in seawater samples collected around the Svalbard archipelago ^{99}Tc activity ranged from 0.10 to 0.20 Bq m^{-3}. Comparison of these values with earlier observations (Gwynn et al., 2004) indicated that seawater activity concentrations for 2005 were generally lower than those reported for same region in 2000 and 2001, but comparable with values for 2004 (NRPA, 2006b). In 2006, the average activity concentration of ^{99}Tc in seawater from the Barents Sea was slightly lower (0.1-0.2 Bq m^{-3}) than that reported in 2005 (NRPA, 2008b; IMR, 2009). Due to the reduction in discharge of ^{99}Tc from Sellafield since 2003, the levels of this radionuclide are expected to continue to decrease.

$^{239+240}$Pu activity concentrations of in seawater from the Barents Sea collected in 2005 ranged from 1.8 to 20 mBq m^{-3} (Figure 4.4.14), with the highest values observed in seawater collected off the coast of Scotland, showing that Sellafield is a source to plutonium in the North Sea, where part of the $^{239+240}$Pu comes from remobilised plutonium from contaminated Irish Sea sediments (NRPA, 2007c). The values of $^{239+240}$Pu observed in 2005 were generally lower than those observed in 2001 (Gafvert et al., 2003).

Activity concentrations of ^{241}Am in seawater from the Barents Sea in 2005 ranged from 0.8 to 19 mBq m^{-3} (Figure 4.4.14.). The ^{241}Am found in the water column today, can be due to both the present discharge from Sellafield of ^{241}Am and from the decay of ^{241}Pu resulting from earlier discharges and global fallout. In 2006 the activity concentrations of ^{241}Am in seawater from the Barents Sea ranged from 1.3 to 19 mBq m^{-3}. With the exception of two samples, the activity concentrations of ^{241}Am in the Barents Sea were similar to those observed in 2002 (NRPA, 2008b).



(a) (b)

Figure 4.4.13. Activity concentration (Bq m^{-3}) of ^{99}Tc (a) and ^{137}Cs (b) in seawater samples collected in the Barents Sea in 2005 (NRPA, 2007).

The activity concentration of ^{137}Cs in the Barents Sea surface water in 2005 (Figure 4.4.13) and 2006 varied from 1.4 to 4.4 and 0.6 to 3.7 Bq m^{-3}, respectively (NRPA, 2007c; IMR, 2009). In 2005 ^{137}Cs activity concentration in sediment samples ranged from 0.4 to 9.9 Bq kg^{-1} (d.w.). Activity concentrations of ^{137}Cs in surface water and sediments were similar to values observed in 2003 (NRPA, 2007c). ^{137}Cs in sediments from open Barents sea and the fjords in Troms and Finnmark provinces measured in 2007 varied from below detection limits up to 14,0 Bq kg^{-1} (d.w.) Values were highest in the fjords, probably as a result of draining from land (IMR, 2009).

Activity concentrations of ^{90}Sr in surface water from the Barents Sea in 2005 ranged from 1.0 to 2.7 Bq m^{-3}, which is similar to the levels observed in 2002 (NRPA, 2007c).

$^{239+240}$Pu activity concentrations of in seawater from the Barents Sea collected in 2005 ranged from 1.8 to 20 mBq m^{-3} (Figure 4.4.14), with the highest values observed in seawater collected off the coast of Scotland, showing that Sellafield is a source to plutonium in the North Sea, where part of the $^{239+240}$Pu comes from remobilised plutonium from contaminated Irish Sea sediments (NRPA, 2007c). The values of $^{239+240}$Pu observed in 2005 were generally lower than those observed in 2001 (Gafvert et al., 2003).

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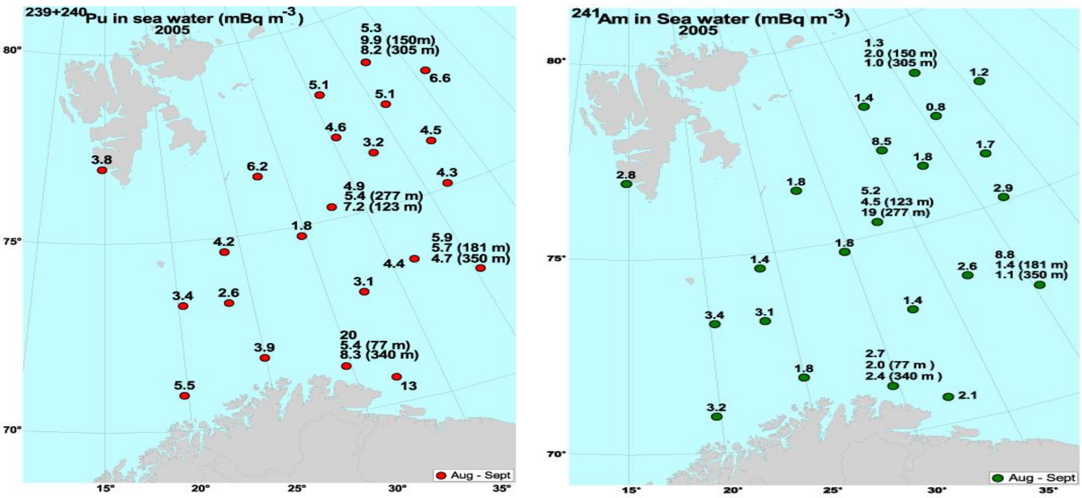


a) (b)

Figure 4.4.14. Activity concentration (Bq m^{-3}) of $^{239+240}$Pu (a) and ^{241}Am (b) in surface water samples from the Barents Sea and along the coast in 2005 (NRPA, 2007).

As reported earlier, produced water from offshore oil production may contain elevated concentrations of especially naturally occurring ^{226}Ra and ^{228}Ra (NRPA (2005a). Activity concentrations of ^{226}Ra in seawater from the Barents Sea in 2005 ranged from 0.4 to 2.3 Bq m^{-3} (Figure 4.4.15) which is close to the reported typical activity concentrations of ^{226}Ra in Atlantic surface water - around 1.3 Bq m^{-3} (IAEA, 1990). Activity ratios of ^{228}Ra/^{226}Ra were generally below 1, with the lowest ratios found in arctic water. In 2004 Norwegian data concerning produced water discharges from installations in the Norwegian sector of the Norwegian Sea was used to determine any potential impact of ^{226}Ra and its daughter products ^{210}Pb and ^{210}Po on biota in the Barents Sea. Modelled calculations demonstrated that contributions to dose from these radionuclides were minor and could not be separated from natural variations of naturally occurring concentrations of the same radionuclides (Brekken et al., 2004).

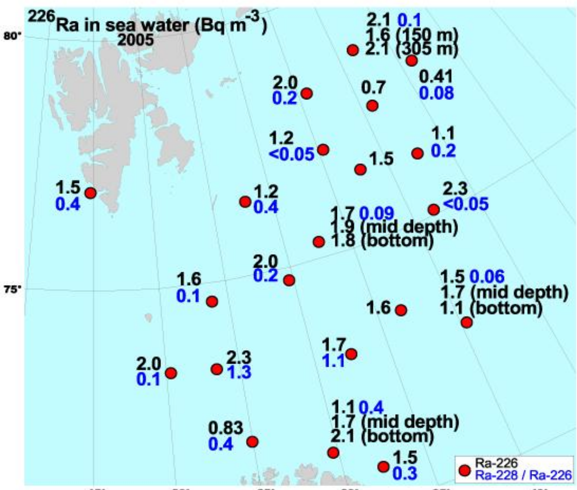


Figure 4.4.15. Activity concentration (Bq m^{-3}) of ^{226}Ra and activity ratios of ^{228}Ra/^{226}Ra in seawater from the Barents Sea in 2005 (NRPA, 2007).

Seafood

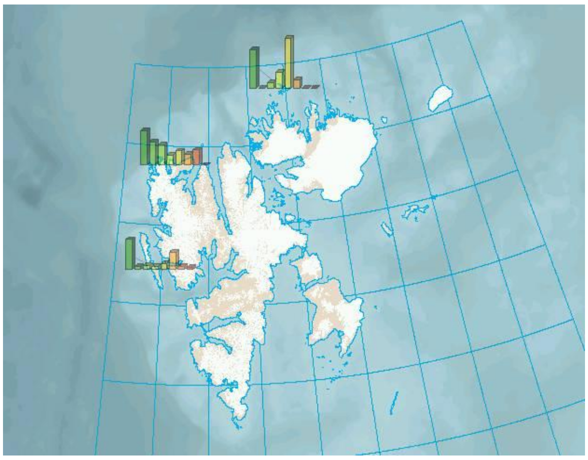
In 2005 the activity concentrations of ^{137}Cs in different fish species from the Barents Sea varied between 0.1 and 0.31 Bq kg^{-1} (w.w.). In cod from the Barents Sea the activity concentration of ^{137}Cs have been analyzed annually since 1992. All obtained values have been lower than 1 Bq kg^{-1} w.w. (with most values lower than 0.5 Bq kg^{-1} w.w), with a slight decreasing trend observed over the period 1992 - 2005(NRPA, 2007c; IMR, 2009).

4.4.2.5 Current status and trends for marine litter

Knowledge about the amount of marine litter in the area, including how vessels handle their waste, is limited. It is therefore difficult to calculate the amount of litter respectively delivered to waste stations on land, burned on board of ships or dumped in the sea.

The major source of marine litter is discharges of waste from ships. The amount of litter along the Norwegian coast is used as an indicator to measure the level of the litter problem. Monitoring done at tree beaches at Svalbard shows a decreasing trend of waste from 2001 to 2008, but the data material is not good enough to draw any conclusions (Figure 4.4.16).

On the Russian side, in Kislaya bay of the Kola gulf large areas of the sea bottom are covered with debris dumped from ships.



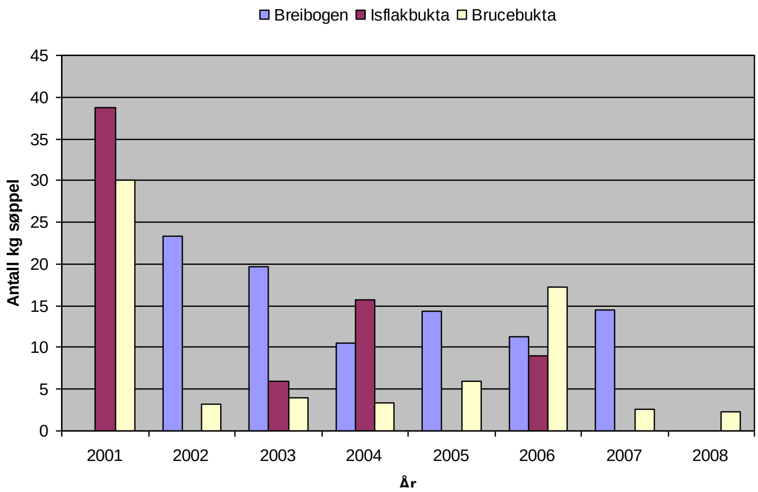


Figure 4.4.16. Yearly amount of litter that have driven on three beaches (Breibogen, Isflakbukta, Brucebucta) at Spitzbergen from 2001-2008. Figures from Sunnanå et al. 2009.

The safety of operating NPPs in the North (the Kola Nuclear Power Plant in particular). In 2006-2008 the greatest part of the Norwegian support has gone into improving and maintaining the safety at the Kola NPP (Action plan, 2009). In 2002 a report on the assessment of potential long-term consequences of hypothetical accidents at Kola NPP was published under the joint Russian-Norwegian Expert Group (NRPA, 2002).

Development, use and export of Floating Nuclear Power Plants (FNPP) in the Arctic, FNPPs are being developed at least partly as commercial products and estimates of planned units are difficult to make. The FNPP's may be operated for a variety of purposes: civilian power/heat generation, provision of a power for desalination of salt water, etc (see Ch. 5.2).

The oil and gas industry can be a major source of "technologically enhanced naturally occurring materials" (TENORM) through the discharge of produced water and descaling activities. Recent assessments suggest that this industry is likely to expand in the Arctic.
Other issues are the presence of nuclear powered military and civilian vessels operating in the region, nuclear icebreakers and their associated facilities, transport of nuclear materials through the region.

Possible effects of climate change on distribution and contents of radioactive substances are described in Ch. 4.6.

4.4.2.6 Expected state in the near future

Based on the current knowledge we have no reason to believe that the pollution situation in the Barents Sea will change considerably in the near future. However, we need to develop long-time series for pollution to make more secure predictions in the future. Changes in the long-range transportation of pollution to a great extent depend on international regulations of use, the amount of releases and the effectiveness of their implementation. The expected increase in marine transport and oil and gas activity may contribute to an increase in operational discharges, marine littering, illegal discharges and also increase the risk for acute oil spill. However, if there are no acute oil spills, we do not think that the pollution situation will change in near future and that long term effects are more likely (see chapter 4.6).

Climate change may have consequences on the pollution situation in the Barents Sea. The routes and mechanisms by which persistent organic pollutants, heavy metals and radionuclides are delivered to the area are strongly influenced by climate variability and global climate change (see chapter 5).

Although presently a general tendency to decrease is indicated for all the radioactive substances in the Barents Sea, a risk related to the several existing and potential sources of radioactive contamination in the region that could affect the Barents Sea area should not be underestimated. In particular, areas of concern are:

- Removal of radioactive strontium batteries (RTGs) in lighthouses in Northwest Russia. RTGs pose radiation hazards. Besides, a number of attempted thefts have shown that the radioactive sources can go astray. Thus, by the end of 2008, 169 RTG's around the

Barents Sea were removed as a part of a bilateral agreement between Norway and Russia (NRPA, 2005a; NRPA, 2006c; NRPA, 2007b). The removal of remaining 11 devices was in progress in 2009 (see Ch. 5.2).

- The decommissioning of nuclear submarines in Northwest Russia, including handling of radioactive waste or spent nuclear fuel and transport to safer places. The submarines represent a potential danger for accidents and constitute a threat to the marine environment (an example is the sunken submarine K-159 in the Barents Sea) in addition to presenting a risk for the abuse and proliferation of radioactive material. The work on safe decommissioning is in progress (see Ch.5.2).
- The maintenance of temporary radioactive waste storage facilities at Andreev Bay, Gremikha, (on the Kola Peninsula), Lepse storage vessel (in the Kola Bay) and transport of spent fuel and radioactive wastes from these facilities to safer storage sites. The facility at Andreev Bay houses large quantities of spent nuclear fuel from approx. 100 nuclear submarines, as well as solid and liquid radioactive waste. In recent years a broad international partnership led by Russia has been developed to manage the challenges these facilities poses. From the Norwegian side, a large number of measures have been carried out since 1997 in order to improve the situation and prevent radioactive contamination of the marine environment as well as to develop improved regulatory documents. Gremikha was mainly used for reactors from decommissioned submarines, but also holds rods and extracted parts from old submarines. Plans on transport of spent nuclear fuel and radioactive wastes from Andreev Bay and Gremikha, and decommissioning of Lepse Floating Maintenance Base are presented in Ch. 5.2.
- The safety of operating NPPs in the North (the Kola Nuclear Power Plant in particular). In 2006-2008 the greatest part of the Norwegian support has gone into improving and maintaining the safety at the Kola NPP (Action plan, 2009). In 2002 a report on the assessment of potential long-term consequences of hypothetical accidents at Kola NPP was published under the joint Russian-Norwegian Expert Group (NRPA, 2002).
- Development, use and export of Floating Nuclear Power Plants (FNPP) in the Arctic, FNPPs are being developed at least partly as commercial products and estimates of planned units are difficult to make. The FNPP’s may be operated for a variety of purposes: civilian power/heat generation, provision of a power for desalination of salt water, etc (see Ch. 5.2).
- The oil and gas industry can be a major source of “technologically enhanced naturally occurring materials” (TENORM) through the discharge of produced water and descaling activities. Recent assessments suggest that this industry is likely to expand in the Arctic.
- Other issues are the presence of nuclear powered military and civilian vessels operating in the region, nuclear icebreakers and their associated facilities, transport of nuclear materials through the region.
- Possible effects of climate change on distribution and contents of radioactive substances are described in Ch. 4.6.

4.4.3 Oil and gas activities

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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 witch might influence near-shore areas, especially in ecologically valuable areas like the Lofoten-Islands, the Polar front, Pechora Sea. In addition, the Polar Front is also a sensitive area.

4.4.3.1 Seismic surveys

As described in chapter 2.6.3, 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 30 km 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 known.

4.4.3.2 Operational discharges

As mentioned in chapter 2.6.3 results from environmental monitoring have so far shown no effects from operational discharges into the water column.

4.4.3.3 Accidental discharges

As described in chapter 2.6.3. there has been no significant accidental discharge of oil or chemicals in the Barents Sea so far.

4.4.3.4 Physical disturbance of the sea bed- habitat reduction

As described in chapter 2.6.3, effects on bottom habitats from oil and gas activities are limited to the Snøhvit field and are small also within this field

4.4.3.5 Emission to air

Offshore oil and gas production will contribute to emission to air of CO_2, NO_x, non-methan volatile organic compounds (NMVOC), methane, and SO_2. Emission to air from petroleum production occurs from energy production, flaring of gas from well testing and from venting (release of unburned gas from pipes and valves in the processes during normal operations or safety reasons). Flaring of associated gas during oil production is not permitted.

The impact of this emission is discussed in chapter 4.4.2 – pollution.

4.4.3.6 Expected situation in the near future (5 years)

It is expected that two new wells will be drilled in the Norwegian and Russian sectors of the Barents Sea in 2009.

For the period up to 2010, Russian authorities plan to award 20 prospective areas in the Barents and Pechora seas. There are distributed over six tenders who are located in the areas with the proven deposits of hydrocarbons.

According to the scientific forecast, starting in 2010, there will be up to 1 million tons of oil and 50 billion cubic meters of gas extracted in the Russian part of the Barents Sea. Dmitrievsky and Belonin (2004) have estimated that the production probably will increase to 30 million tons of oil and 130 billion cubic meters of gas by 2020.

The Barents Sea oil complex will be formed based on the supplies of the currently known fields (oil: Prirazlomnoye, Medynskoe, Varandey, Dolginskoye, and oil/gas condensate: Severo-Gulyaevskoe) and will develop according to the exploration and development of nearby fields. Extracted amounts of oil from those structures and fields are 600-700 million tons. Basis of the gas complex of the Barents Sea are Shtokman and Ledovoe gas condensate fields along with the gas field Ludlovskoe. Their total annual supplies are estimated to be 400 billion cubic meters and create a reliable resource base.

For transportation of gas condensate from the Shtokman field, there are plans to build underwater pipeline, with the length of over 800 km that will lead to disturbance of the bottom sediments and coastal line.

Risk of accidental discharges

Below, risk of accidental discharges from oil and gas is discussed together with risk from discharges from ship transport. Thus, the analyses below involve more than the risk from oil and gas activities alone. Current status for ship transport is dealt with in chapter 4.4.4.

An attempt to evaluate the rate and volume of possible accidental oil spills in the Russian Western Arctic seas based on the average worldwide oil spill statistics was made by Patin (2008a). The results of generalization of relevant statistical data are given in Table 4.4.4. It should be noted that this is based on one of several methods and that other methods could have produced different results. In particular, as the study is based on worldwide data, it should be interpreted with special caution for any regional and local level. It should also be noted that risk assessments are an area with considerable debate about methodology.

Realization of actual as well as planned activity of Russian oil industry in the Barents Seas as a part of the Arctic seas suggests a wide list of objects and situations that could generate accidental oil spills. Table 2 presents assessment of possible amount and rate of accidental oil spills in the process of exploration and exploitation of oil fields in Western Arctic (Patin 2008a).

Table 4.4.4. 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 5000 tonnes.

Assessments in Table 4.4.5 suggest that probable total input of oil into marine environment only due to accidents in the process of development of hydrocarbons fields in the Western Arctic seas will reach about 23 000 tones by 2030 with tanker accidents being the main source. Taking into account routine (operational) releases as well as illegal discharge of oil wastes during all kind of shipping (which are comparable with the amount of accidental spills (Patin, 2008b)), total oil input by 2030 is estimated to be about 40 000 tones. One should also take into account a planned multiple (up to 10 times) increase in oil export by tankers from Russian Arctic terminals which is now about 15 million tones per year. Meanwhile, during 30 years of oil transportation from Arctic the total amount of exported oil will probably exceed 1 milliard tones. Based on all these circumstances, there is a reason to predict that a total (cumulative) input of oil in marine environment by 2030 will reach 100 000 tones.

As to the rate (probability) of oil spills, this parameter is greatly variable in dependence of amount of spilled oil and the current situation. By 2015 maximum capacity of oil transportation from the Western Arctic by tankers is estimated to reach a level of about 125 million tones/year (Bambuhak, Frantzen, 2009). Worldwide loss is estimated to be about 30 tones per 1 million tones of transported oil (Table 4.4.4). From this, the total probable amount of oil spills is estimated to be at the level of 3750 tones/year.

Based on this estimate and worldwide statistical parameter for large spills (4×10^{-3} spills per 1 million tones of transported oil) (GESAMP, 2007) one may predict that an oil spill rate for this situation will be about 0.6 large spills (over 5000 tones) per year. According to Vorobiev et al. (2005), catastrophic oil spills with serious ecological effects in the Arctic seas may occur as often as every 5-10 years. However, it should be noted that no major oil spill has so far occurred from marine oil transportation in the Barents Sea.

From a biogeographical point of view, the highest risk of incidents and the most serious oil spill impacts seem to be attributed to numerous bays, inlets, creeks and marches of Arctic coastal zone. These areas are distinguished by high biomass and productivity and in Russia many of them have been given the status of “Especially protected Arctic marine territories”.

Table 4.4.5. 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.

	Total amount of spill		
Spill sources	**tonnes**	**%**	**Rate of large oil spill (over 5005 tonnes)**
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	$4x10^{-3}$ spills per 1 million of transported oil
Total	22800	100	

* Including spills in ports and oil terminals

Overall risk

In the context of risk analysis, risk is often calculated as the product of probability and consequence. Risk analysis is a decision support tool and an integral part of risk management. Analysis seek to understand how a dangerous situation can arise and develop, with a view to implement the most relevant measures where they will be most effective in preventing risks from resulting in actual accidents and limiting the consequences if an accident does 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.

A number of models and analyses are used today 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 make use of risk management in order to prevent oil spills, and must establish adequate barriers or emergency response system. The 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 any oil spills. For management purposes, it is most important to develop a common understanding of risk, including an understanding of mechanisms that create risk, and of the limitations and uncertainty of our knowledge.

4.4.4. Maritime transport

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4.4.4.1 Impact from operational discharge (oil, contaminated water, ballast water)

As described in chapter 2.6.3, no major impacts have been registered from operational discharges of oil and chemicals from anti fouling systems from ship transport.

The day-to-day impacts of shipping on the environment are caused by ordinary operational discharges. The routine discharges to the sea that have most impact on the environment are operational discharges of oil and the release of organotin compounds from anti-fouling systems.

The 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 the impacts in the Barents seas.

To protect ships against corrosion, zinc anodes are used in addition to special paints. If zinc anodes are used in ballast tanks, the 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. No such impacts have so far been registered.

4.4.4.2 Impacts from emissions to air

The maritime transport contributes to emission to air of CO_2, NO_x, non-methane volatile organic compounds (NMVOC), methane, and SO_2. The impact from this emission is discussed in chapter 4.4.3 – pollution.

4.4.4.3 Introduction of alien species, through fouling of the hull or discharge of ballast water

As described in chapter 2.4.10, alien 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 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 the Northern Sea Route came into the agenda. During the next 5 years, the northern Timano-Pechora oil fields (Yuzhno Khylchuyu and others) and

Varandey terminal will transport about 10 million tons of crude a year and play a major role in oil shipments increase from the Russian Barents. The Prirazlomnaya platform should come on place in the Pechora Sea and produce 7 million tons of oil that will be shipped for export. When the newly adopted plan for development of Murmansk Transportation Complex is realised, we will see more oil and refined products coming north by the railway. The Table 4.4.6 gives an overview of existed and prospected capacities of the main terminals shipping Russian crude oil and petroleum products for export.

Table 4.4.6. Existing and prospected capacities of main Arctic terminals offloading Russian crude oil and petroleum products for export (in thousands tons) (Bambulyak and Frantzen 2009).

	Capacity		
Terminal locations	**2002**	**2008**	**2015**
Ob Bay, Kara Sea	500’	600’	*3 000’*
Varandey, Pechora Sea	1 500’	12 500’	*12 500’*
Prirazlomnoye, Pechora Sea	-	-	*7 500’*
Arkhangelsk, White Sea	2 500’	4 500’	*7 000’*
Vitino, White Sea	4 000’	10 000’	*12 000’*
Teriberka (LNG), Barents Sea	-	-	*7 500’*
Murmansk, Barents Sea	2 000’	8 000’	*8 000’*
Mokhnatkina Pakhta, Barents Sea	-	2 500’	*5 000’*
Lavna, Barents Sea	-	-	*25 000’*
Pechenga, Barents Sea	-	-	*30 000’*

The LNG plant at Melkøya has begun to ship gas condensates, although certain challenges still prevent full-scale production. A gradual stepping up of production towards full capacity is expected. The prognoses for natural gas production at Melkøya are very uncertain, but one expects that about 5 million tons of LNG, LPG and condensate can be shipped out per year when the plant is running at full capacity. This would result in about 70 annual shipments of natural gas from Melkøya.

An increasing share of container ships and bulk cargo can be expected if the published plans for the development of the terminals in the Murmansk region and/or Narvik are realised (Bambulyak and Frantzen 2009).

From 2012 and the next five years several gas and oil fields might come on stream. Seen from the west Goliat is planned to go on stream in late 2013, Prirazlomnoye about the same time, then Shtokman and in the Kara Sea, huge gas fields on Yamal (Bovanenkovo and others) might ship gas and condensate from Kharasavey if the proposed LNG-terminal is built.

From 2014 (at the earliest), shipments of LNG and gas condensates from the Shtokman field in the Russian sector of the Barents Sea are expected. This is the world's largest known offshore gas field to be set in commercial production, with a planned production level in the first phase of 22.5 billion m3 of natural gas that will be split and partly pumped south to Nord Stream pipeline, and partly shipped as LNG. This will involve 280 annual shipments of natural gas through the area. The prognoses for the second and the third construction phases are uncertain, but the Russian company Gazprom estimates that the output can be increased to 70 billion m3 per year.

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, and depend on whether or not Russia decides to shift the focus of its oil exports towards the USA. Assuming that Europe remains the primary market for Russian oil, there are estimates that forecast a linear increase from 15 million tons in 2010 to 50 million tons in 2025. Another forecast, assuming that USA becomes the primary market, estimates a gradual increase from 15 million tons in 2010 to up to 100 million tons after 2020.

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 of this type of vessel might thus implies a higher risk of acute pollution events unless considerable measures are put in place to mitigate this.

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Shipping traffic will increase in correlation with petroleum activities in the region. If the extent of petroleum activities increases considerably, the volume of petroleum-related shipping traffic will also increase, and as a consequence also the risk of acute pollution from this traffic, unless considerable measures are put in place to mitigate this.

The Ballast Water Management Convention signed in 2004 regulates discharges of Ballast water and sediments. This is not in force, but early 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 alien 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, currently unplanned 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 will reduce the risk of oil spills associated with maritime transport by half from 2003 to 2020, and that the environmental consequences in 2020 will be comparable with those in 2003.

4.4.5 Other human impact

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4.4.5.1 Tourism

As described in chapter 2.6.3, cruise-ship tourism may have impact on behaviour of marine mammals. Due to expected climatic changes that will open new area for sailing because of ice melting, one can also expect increasing pressure from tourism in this open area. The arctic region, therefore, is under steadily increasing pressure from tourism.

4.4.5.2 Bio-prospectation

As described in chapter 2.6.3, bio-prospectation does not have impact on the ecosystem in the Barents Sea today.

4.4.5.3 Aquaculture

As described in chapter 2.6.3, aquaculture may affect the ecosystem when farmed fish escape and interact with native fish, through spread of pathogens and through pollution. The total impact from such effects in the Barents Sea today is not known.

4.5 Conclusions about state of the ecosystem

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The aim of this subchapter is to summarise key features of the state of the Barents Sea ecosystem and discuss what aspects of the ecosystem are likely to be influenced by anthropogenic impacts. A discussion is also undertaken regarding possible developments of the ecosystem in the future. The chapter takes the ecosystem perspective, and will consequently focus on ecosystem status, function and processes. The anthropogenic driver that currently has the largest documented impact on the functioning of the Barents Sea ecosystem is harvesting. In addition, the ecosystem is affected significantly by climate changes. and the interaction between harvesting and climate change. Special emphasis is therefore given to these factors in the discussion below. The climate changes that have been observed in recent years are in part due to the effect of anthropogenic emissions of CO_2 and other greenhouse gases, but they also represent natural variation in the system on long-time scales. Development of oil and gas production (see chapter 4.4.2.), increased maritime transport (chapter 4.4.3.) and ocean acidification due to climate warming (see chapter 4.6.2.) may become additional factors that probably will affect the system in the future.

The Barents Sea is a shelf ecosystem situated at the border between the Arctic and North Atlantic Oceans where water moves from the North Atlantic into the deep Arctic Ocean basin. From the Arctic Ocean perspective, the Barents Sea is a highly productive, deep, inflowing shelf sea (Carmack and Wassmann, 2006). Compared to the other North Atlantic shelf ecosystems, however, the Barents Sea has relatively low productivity and low biodiversity (Frank et al., 2007). However, south of the polar front, high primary production and advection from the Norwegian Sea translate into high biomass of zooplankton and large stocks of small pelagic fish that support one of the largest fisheries in the world. The Norwegian coastal current carries fish larvae into the Barents Sea and the southern part of the region is the nursery area for important commercial species such as the NEA (North East Atlantic) cod [MSOffice1]and the NSS (Norwegian Spring Spawning) herring The vast areas north of the polar front are characterized by highly variable and seasonal ice cover. Primary production is generally low but ice melting during summer stratifies the water masses and initiates a concentrated, short-lived phytoplankton bloom that supports high concentrations of zooplankton. These areas are targets for the northbound feeding migrations of capelin , cod, seabirds and marine mammals in late summer and early autumn.

The Barents Sea has been harvested by humans for centuries (Chapter 2.6.3). Similar to other continental shelf areas (Jackson et al., 2001; Lotze and Worm, 2009), hunters and fishermen have targeted the high-value/low-cost catch. The targeted species have often been slow growing, large animals, on the top of the food chain (Lotze and Worm, 2009). The result has been a sequential extirpation of large predatory fish, seabirds and sea mammals. This has almost certainly resulted in fundamental changes in the ecosystem (see e.g. Jackson et al., 2001; Lotze et al., 2005). For example, the ecosystem that once supported vast baleen whale and harp seal populations in the Barents Sea (see Weslawski et al., 2000; Skaug et al., 2007) was certainly different from the present one. Today, cod is the dominant predator in the Barents Sea. This is similar to the other North Atlantic shelf ecosystems (Link et al., 2009). However, high fishing pressure has, in several of these systems, reduced the populations of cod to very low levels. There has been a subsequent increase in the populations of small pelagic forage fish species such as capelin, herring and sprat (*Sprattus sprattus*) in systems such as the North Sea, the Baltic Sea and the Scotian Shelf (e.g. Frank et al., 2005; Casini et al., 2009). Large stocks of small pelagic fish might be responsible for reducing the recruitment of cod through either predation on eggs and larvae (Swain and Sinclair, 2000; Bakun, 2006), or through competition for larval food (Casini et al., 2009). Such positive feedback mechanisms result in stable ecosystem shifts from a predator (cod) dominated state to a prey (herring or capelin) dominated state (Bakun, 2006).

Fluctuations in ocean climate have profound effects on northern shelf ecosystems (Ottersen et al., 2009). The main mechanisms work through effects on the recruitment of major fish stocks with large consequences for fisheries, and through changes in the large-scale distribution of species which may influence community structure dramatically (Beaugrand et al., 2008; Ottersen et al., 2009). In the Barents Sea, climate change will in addition affect the distribution of sea ice, with large consequences for primary production (Ellingsen et al., 2008) and for ice-dependent flora and fauna (e.g. Kovacs and Lydersen, 2008). Perturbations from climate anomalies propagate through the food web and generate more or less abrupt changes in the ecosystem (de Young et al., 2008). For example, in the North Sea, climate influences have profound effects on the plankton community through changes in phenology (Edwards and Richardson, 2004) and large-scale biogeography (Beaugrand et al., 2002). Recent warming has therefore resulted in a mismatch between the timing of cod spawning and the peak in the abundance of food for larval cod. Combined with a small parent stock, this has severely impaired the recruitment of North Sea cod in recent years (Beaugrand et al., 2003).

Through complex effects on life-histories, individual behaviour and interactions between species, perturbation from harvesting and climate changes can have subtle effects on the ecosystem, resulting in more or less unpredictable changes. By canalizing ecosystem interactions through alternative pathways, the ecosystem might compensate for the perturbations and thus be quite resistant. However, when changes occur they might be more or less abrupt, and through positive feedback mechanisms, the ecosystem can be locked in a new alternative state even if the causes of the perturbations cease (see e.g. Scheffer et al. 2001, Willis 2007, de Young et al. 2008). *Predictable*, *resistant*, and *resilient* ecosystems are generally associated with *high biodiversity* (Worm et al. 2006), *high productivity* and *bottom-up regulation* (Frank et al. 2006, 2007). Compared to the other North Atlantic shelf ecosystems the Barents Sea has *low productivity*, *low biodiversity* and is *top-down regulated* (Frank et al. 2007, Petrie et al. 2009). Consequently, the Barents Sea is likely to be more vulnerable to perturbations, and a careful harvesting strategy is strongly recommended (Petrie et al. 2009). However, contrary to the Baltic Sea, the North Sea and the Scotian Shelf, the Barents Sea has not gone through any major system changes in recent years, and at present the system seems to be quite resistant to the current level of anthropogenic drivers.

4.5.1 Effects of climate change

Studies of how natural decadal and multi-decadal climatic fluctuations have affected marine ecosystems (e.g. Ottersen and Stenseth, 2001; Titov, 2001; Boitsov and Orlova, 2004; Titov and Ozhigin, 2005; Drinkwater, 2006), have provided insight into what can be expected given the suggested continued warming of the Barents Sea (Ellingsen et al., 2008). Historically, an increase in temperature of only 2 ºC has been documented to have significant impacts on oceanographic features (frontal zones, salt and heat budgets, thermohaline circulation) that drive ecosystem structure and function (Renaud et al., 2008). Changes in these drivers are already apparent; but it is difficult at present to separate natural fluctuations from human induced climatic changes.

It is expected that thinning of the annual sea ice will continue. A marked increase in the melting of sea ice during summer will result in an increased width of the area with seasonal ice cover (Ellingsen et al., 2008). Thus, the area covered by annually formed ice will reach farther into the Arctic Ocean (Carmack and Wassmann, 2006). Reduced sea ice cover and thickness combined with a prolonged ice free period may increase primary production (Ellingsen et al., 2008), and support an increased biomass of benthos in the eastern and northern parts of the Barents Sea (Cochrane et al., 2009). A complicating factor when predicting how primary productivity will respond to a warmer climate is that warming of the water column and the associated increase in melting of sea ice may lead to increased stratification of the water column, thus reducing supply rates of nutrient because mixing of nutrient rich deepwater layers with layers higher in the water column where primary production occurs is reduced. Expansion of the area covered with seasonal ice will nevertheless increase the biological production associated with the marginal ice zone (Carmack and Wassmann, 2006). Specifically, nutrient-limited diatom blooms that follow ice melting and stratification of the water masses in the summer (Wassmann et al., 1999; Falk-Petersen et al., 2000) will be positively impacted. These blooms support high densities of suspension-feeding zooplankton and large aggregations of forage fish (i.e. capelin) as well as top predators such as cod, polar bears, whales, seals and seabirds. However, reduction in the extent of sea ice will have negative impacts on ice-associated flora and fauna. Of special concern is the expected negative impacts on several ice-dependent mammal species which have already been severely reduced by human over-harvesting (Kovacs and Lydersen, 2008; Wiig et al., 2008).

The biomass of zooplankton in the Barents Sea is thought to be linked to climate-forced transport of warm Atlantic Water from the Norwegian Sea (Skjoldal et al., 1992; Boitsov and Orlova, 2004). Climate warming might increase the advection of zooplankton. However, recent studies of the zooplankton-advection relation (Ellingsen et al., 2008; Stenevik and Sundby, 2007; Tande et al., 2000; Dalpadado et al., 2003; Loeng and Drinkwater, 2007) show that this is a complex process that needs more study.

Recruitment of herring and cod has been shown to be positively related to sea temperature. Higher than normal sea temperatures in the Norwegian and Barents Seas increase the survival of larvae and juveniles, and thus the chance of producing strong year-classes (Ottersen and Sundby, 1995; Toresen and Østvedt, 2000; Klyashtorin et al., 2009). The mechanism behind this relationship is not completely known, but it is probably related to increased abundance of food for the fish larvae during warm years (Ottersen and Stenseth, 2001). It is thus reasonable to expect that increased sea temperature (within limits) will result in higher abundance of juvenile NSS herring and NEA cod in the Barents Sea (Loeng and Drinkwater, 2007). In the 2000s, the recruitment of these species has been less variable than in previous years; this might be related both to high spawning stock levels and high sea temperatures.

Possible consequences of global climate change for the fishing industry exploiting cod and capelin stocks in the Barents Sea have been discussed in some recent scientific publications. According to Titov and Ozhigin (2005) and Titov et al. (2006), the Barents Sea ecosystem will be dominated by the boreal oceanic system, the range of climate variations will be reduced and the cyclic ecological succession will be limited by the two "late" phases characterized by weak cold advection and low ice coverage. In this case no strong capelin year classes can be expected, and the abundance of cod year classes will probably fluctuate between middle and low levels. However, if there will be drastic changes in the Barents Sea ecosystem, involving considerable changes in fish species composition and distribution as well as changes in migration patterns of commercial stocks, this pessimistic scenario may not come true.

It should be noted that 0-group fish may play a significant role in the ecosystem, both as predators and as prey. In years with high abundance, the biomass of the most abundant species may add up to more than 1 million tonnes. Given the high consumption per body weight, the prey consumption by 0-group fish can be significant compared to the consumption by pelagic fish, particularly in the southern and central areas where little capelin is found. This suggests that keeping high spawning stocks may have a positive effect on the ecosystem even though the gain in fish recruitment may be limited compared to at intermediate spawning stock sizes.

Warm periods in the North Atlantic have been associated with rapid northward displacements in the distribution of fish (Drinkwater, 2006) and invertebrates (Renaud et al., 2008). During the period of arctic warming (1930-1950), Atlantic species uncommon to the Barents Sea were found in the region (Zenkevish, 1963). In recent years, distributional changes associated with a warmer climate, have already taken place (see e.g. Sundby and Nakken, 2008).

Based on experience from the warm period in the Barents Sea during the 1920s and 1930s (see Drinkwater, 2006), it can be expected that the major fish species will continue to expand north and east in the Barents Sea. This includes NEA cod, NEA haddock (*Melanogrammus aeglefinus*), NSS herring and capelin. Major spawning areas for NEA cod will move northwards along the Norwegian coast from the Lofoten area to Troms and Finmark (Sundby and Nakken, 2008). Blue whiting (*Micromesistius poutassou)*, a boreal species, occurred in the Barents Sea in large quantities in 2001-2007, but the abundance of this species has now returned to a low level. This "outbreak" was probably related both to a large stock and high sea temperatures. One could also expect that other boreal species such as mackerel (*Scomber scombrus*) and grey gurnard (*Chelidonichthys gurnardu*) will appear more regularly in the western and southern part of the Barents Sea (Yaragina and Dolgov, 2009). So far, however, the mackerel has extended its distribution northwards in the Norwegian Sea rather than moving into the Barents Sea (ICES 2008a and references therein). Benthic taxa characteristic of arctic shelve seas may be displaced northward by advancing boreal taxa, and left with few refugia north of the Arctic Ocean shelf break (Renaud et al., 2008).

In the North Sea and adjacent shelf areas, warming has been associated with a change in plankton communities from cold to warm water species (Beaugrand et al., 2002). Similar changes can be expected in the Barents Sea where arctic species might be replaced by more boreal species. The plastic life-histories of the *Calanus* species are expected to change as a response to warming (cf. chapter 2.4.3). Such changes might have large impacts on the "match" with the phytoplankton bloom, and with spawning of major fish stocks, particularly those whose smallest life stages depend on *Calanus* for food (see Edwards and Richardson, 2004).

Climate change also increases the pollution loads to the Barents Sea due to increased precipitation, increased run-off from land and changes in the atmospheric transport of contaminants. The observed trend with a steadily decreasing input of organic pollutants during the last decade may thus be broken and the increased concentrations of POPs like PAH and HCB may be the first sign of a climate induced change in long range transport of air-borne pollutants (see also chapter 4.4.2). Changes in water temperatures, ice cover and ocean chemistry (acidification) will also most likely affect degradation processes and uptake of contaminants in biota. However, all direct and indirect effects of climate change can at present not be assessed and the net influence of climate change on contaminant levels cannot therefore be easily predicted.

The current assessment of climate change suggests that warmer temperatures, changes in precipitation and shifts in the presence of snow, ice and water may affect transport of radioactive substances and their routes in the marine environment. For example, movement both into an out of the Barents Sea may become more rapid than today (AMAP, 2009). We may also expect remobilization of radionuclides, including re-suspension and transfer of contaminated sediments from localised sites to the surrounding areas (for example from Chernaya Bay to the Barents Sea). Changes in temperature may also lead to changes in turnover rates of contaminants in cold-blooded animals such as fish.

4.5.2 Effects of fisheries

According to the ICES criteria (ICES 2008b) the stocks of NEA cod, NEA haddock, northern shrimp (*Pandalus borealis*) and capelin have full reproductive capacity and are harvested within sustainable limits. The stocks of NEA Greenland halibut (*Reinhardtius hippoglossoides*), golden redfish (*Sebastes marinus*) and deep-sea redfish (*Sebastes mentella*) have been fished down to very low levels. These threatened species are long-lived and have low potential growth rates. Although the fisheries at present are strongly regulated, the rebuilding of these stocks will take many years. Norwegian coastal cod is of special concern. The spawning stock biomass and recruitment are at historically low levels, and according to the ICES advice, no catch should be taken from this stock in 2009, and a recovery plan should be developed and implemented.

Fishery by-catch is a serious problem in the protection of endangered, long-lived species with low reproductive rates (Hall et al. 2000, see e.g. Casey and Myers 1998). In the Barents Sea, the by-catch of deep-sea redfish in the shrimp fishery has been a serious problem of this type. This has been addressed recently via the introduction of legal limits being set for by-catch, and by using sorting grids in the shrimp fishery. Norwegian coastal cod is taken in the ordinary NEA cod fishery. Several restrictions on the fisheries close to the coast and within fjords have been implemented to reduce the fraction of coastal cod in the catches. The effect of these restrictions is still unknown. Diving seabirds, and specifically auks and sea ducks, are taken as by-catch in the coastal gillnet fisheries (Strann et al. 1991, Zydelis et al. 2009). The by-catch of common guillemots (*Uria aalge*) in the gillnet fisheries for cod in Troms and Finnmark during spring is a special concern (Strann et al. 1991, Christensen-Dalsgaard et al. 2008). The problem is probably highly variable from year to year, depending on the spatial overlap between the fisheries and the aggregations of the birds. In some years, the number of birds taken can be large (Strann et al. 1991), which might have effects on the already threatened population.

Disturbance from trawling and dredging has wide-ranging impacts on the diversity, and productivity of benthic communities (Jennnings and Kaiser 1998). In the Barents Sea, particular attention has been paid to biotic habitats generated by aggregations or colonial growth of single species. Such habitat-generating species are represented by a wide range of taxonomic groups (e.g. *Porifera*, *Polychaeta*, *Cnidaria*, *Mollusca* and *Bryozoa*; see reviews in Jennings 1998, Auster and Langton 1999, Kaiser and de Groot 2000, Moore and Jennings 2000), house a high diversity of associated species, and are examples of whole communities that can be managed within restricted areas. For obvious reasons these biota are seriously threatened by bottom trawling, and there is a strong need for protection. Damage from bottom trawling and other forms of seafloor disturbance (e.g. petroleum activities) is not limited to colonial species, but will impact all species with a life span that does not favor reproduction between disturbance events. More generally, frequent disturbance of soft-sediment communities leads to the proliferation of smaller benthic species with faster life histories. Because the larger species are removed, the depth of bioturbation and habitat complexity is reduced, resulting in a reduced benthic production (Kaiser et al. 2000, Jennings et al. 2001). However, benthic production is also highly dependent on primary production, and temporal changes are often masked by e.g. climatic changes (Jennings et al. 2001). Studies indicate that the benthic biomass in the Barents Sea has been reduced by as much as 70% in some areas (Denisenko 2001, chapter 2.4.4). Parts of this reduction can be attributed to reduced primary production and perhaps increasing populations of invasive opportunistic decapods, king crab (Cunningham 1969; Anisimova et al 2005; Jørgensen and Primicerio 2007) and snow crab, which forage on a wide variety of benthic animals. However, increased bottom trawling is probably also an important factor, and disturbance of benthic communities from bottom trawling might accordingly have a substantial impact on the Barents Sea ecosystem.

Fishing affects the demography of targeted species and consequently imposes selection pressure on the stocks (Olsen et al. 2004, Jørgensen et al. 2007). In the Barents Sea, the onset of the industrial trawl-fishery induced a shift from harvest of old, large NEA cod to younger and smaller fish, as well as increasing the overall harvesting rate. The result has been a marked shift in the age and size distribution of the stock, from a stock dominated by old, large individuals to a stock dominated by young and small individuals (Ottersen et al. 2006). The shift in harvest strategy has also induced a change in selection pressure, favouring earlier maturation, and age and size at spawning have decreased accordingly (Ottersen et al. 2006). This shift may, however, have been less severe than claimed by those authors, as it has recently been shown that the determination of age at maturation by otolith reading has changed over time (Zuykova et al. 2009). The NEA cod is a dominant predator within the

Barents Sea (Dolgov 2009, Yaragina and Dolgov 2009). Cod is a highly plastic and omnivorous predator, which feeds extensively on capelin, krill, northern shrimp, polar cod (*Boreogadus saida*), juvenile herring, and young cod and haddock (Yaragina and Dolgov 2009). Feeding is concentrated to the most abundant and favourable prey item, and changes in the relative abundance of prey items result in a "switch" in feeding preferences (Yaragina and Dolgov 2009). "Switching" to the most abundant prey item stabilize the system by dampening outbreaks in the prey populations. Moreover, at times when prey is generally scarce, cannibalism on younger ager classes quickly regulates the cod population to the availability prey (Hjermann et al. 2004a, Gjøsæter et al. 2009, Yaragina et al. 2009). Frequency-dependent "switching" behaviour combined with facultative cannibalism underline the importance of cod as a predator species with a stabilizing role in the ecosystem (see e.g. Frank et al. 2005, Casini et al. 2009). The fishery-induced change in the abundance and size-distribution of NEA cod has changed its role as a top-predator. Similar to other northern shelf ecosystems, the Barents Sea is therefore likely to be susceptible to large outbreaks and fluctuations in the stocks of small pelagic schooling fish such as capelin and herring.

4.5.3 Interactions and prospects

The combined effects of climate change and fishing are complicated by complex trophic interactions (see e.g. Hjermann et al. 2007). However, based on the present situation, known trophic interactions and ecosystem effects of fishing and climate change, some possible scenarios can be outlined; these are discussed below. Although a continued warming is likely in the longer term, short term cooling might occur due to natural fluctuations, and medium and long-term prospects may therefore differ.

Irrespective of temperature development, we have some knowledge about the short-term (<5 year) development, based on the present stock size and age composition of the main fish stocks. The cod stock will stay at a stable, but high, level in the coming years, the recent growth in stock size is not likely to continue as the incoming year classes (2006-2008) are below average. The large capelin stock together with a reasonable amount of other prey should ensure enough food for the large cod stock in the coming years. The haddock stock is at a historic high level, but will probably decrease from 2010 onwards due to reduced recruitment. It is unknown whether haddock, which mainly feed on benthic organisms, will be food-limited at such high stock sizes. There are no strong year classes of herring in the Barents Sea at present, and we do not know when the next strong year class will occur. Several researchers support the view that high herring abundance in the Barents Sea seems to be a necessary but not sufficient condition for a capelin collapse, whereas others suggest that a multitude of factors are involved, including climatic fluctuations, predation from fish and marine mammals and fisheries. Based on the view that predation from herring is an important factor, and taking into account the lag between the occurrence of a strong herring year class and a capelin collapse, a capelin collapse is not likely to happen before 2012.

A large spawning stock, low harvesting and continued warming is favourable for NSS herring, and the stock can therefore be expected to increase further in the future. A large herring stock has a strong impact on the marine environment. NSS herring consume a considerable part of the copepod production in the Norwegian Sea (Dommasnes et al. 2004). An increasing stock is therefore likely to reduce the biomass of copepods, with possible consequences for the biomass of zooplankton that is transported into the Barents Sea. Herring is also an important predator on eggs and larvae of several fish species (Gjøsæter and Bogstad 1998, Godiksen et al. 2006, Segers et al. 2007, Huse et al. 2008). In the Barents Sea, a large herring stock has negative consequences for the recruitment of capelin (Gjøsæter and Bogstad 1998, Hjermann et al. 2004b). Although a high abundance of juvenile herring did not prevent the current capelin “outbreak”, a continued increase in herring might be expected to have long-term effects on capelin by affecting the frequency and amplitude of the capelin fluctuations, and possibly reduce its dominating role in the ecosystem.

If alternative prey is not present, a severely reduced capelin stock will have a strong negative impact on top predators in the Barents Sea, as observed in the late 1980s (Gjøsæter et al. 2009). A low capelin stock might for example have negative impacts on a range of seabird and sea mammal species in the area (Hamre 1994, Sakshaug et al. 1994). For some species, alternative prey such as juvenile herring, polar cod and crustaceans might provide foraging alternatives, but a low stock of capelin generally means that ice-edge feeding top-trophics must travel further to access food (see e.g. Barrett and Krasnov 1996, Barrett 2002). A low capelin stock is also associated with increased cannibalism in cod (Gjøsæter et al. 2009, Yaragina et al. 2009). The adverse effect of cannibalism might be counteracted to a degree by increased cod recruitment due to increased water temperature (e.g. Ottersen and Sundby 1995), and an increased abundance of alternative prey. As long as the harvesting of cod is kept below the long-term sustainable limit, and a large herring stock does not impair cod recruitment, the NEA cod stock might continue to be relatively strong, even with capelin at low levels. Intensive fishing has, however, reduced the cod’s ability to affect the large fluctuations in the stocks of capelin and juvenile herring.

A marked increase in primary production north of the polar front is an expected consequence of continued warming (Ellingsen et al. 2008). This new production will support an increased zooplankton community and enhance benthic production. How the benthic community will respond to the increased input of organic matter, will however, depend partially on how these communities have been impacted by trawling. Capelin is the major consumer of secondary production in the Arctic Barents Sea (Orlova et al. 2002, Dalpadado et al. 2003). A reduced capelin stock might initiate a trophic cascade resulting in an increase in the zooplankton standing stock (see Dalpadado et al. 2003; Orlova et al., 2001), and possibly a subsequent decrease in the biomass of phytoplankton. Reduced consumption by capelin could be compensated for by an expansion and increase in the stock of polar cod (Orlova et al. 2009), and an increase in the abundance of omnivorous and carnivorous crustaceans such as krill and amphipods (see Dalpadado et al. 2001, 2008; Drobysheva and Yaragina, 1990). The response will, however, depend on how these species will be impacted by warming and the continued thinning of sea ice. During the recent periods of low capelin abundance, krill/amphipods and polar cod were apparently unable to compensate for the reduced consumption of zooplankton (see Dalpadado et al. 2003). Moreover, with a reduced capelin stock, less arctic production will be transported to the Norwegian and Murman coasts during capelin spawning. This might have long-term consequences for the coastal ecosystems.

Predictions for the development of the Barents Sea ecosystem on a time scale of more than 5 years are associated with large uncertainties. Although our understanding of the system has increased considerably in recent years, a number of important questions are still unresolved. Some of these are:

- How will warming impact oceanographic drivers of ecosystem function responsible for determining quality, quantity, and timing of primary production?
- How will warming affect the match/mismatch between phytoplankton, zooplankton and the spawning of major fish stocks?
- How will a large NSS herring stock affect the zooplankton community and the recruitment of cod and capelin?
- Will the capelin stock continue to fluctuate?
- How will top-predators respond to changes in the abundance of pelagic fishes?
- Will changes in the abundance of pelagic fishes cause a trophic cascade?
- How will the benthic community respond to changes in organic input, combined with fish trawling, temperature increase and invasive predatory species?

4.6 Some aspects of possible long-term future changes in the ecosystem

As discussed in other chapters of this report, several aspects of the impact that human activities have on the ecosystem are clearly manifested and visible or will likely become so in the near future (see chapters 2.6.3, 4.4 and 4.5). Other aspects may become visible longer time into the future, and this is the topic of the present chapter.

The issues focused here are broad impact on the ecosystem from climate change (4.6.1) and ocean acidification (4.6.2), fishery induced evolution in maturation in Northeast Atlantic cod (4.6.3) and changes in pollution caused by climate change (4.6.4). It should be underlined that this is not a complete list of potentially important long term changes. Putting up such a list would be a major undertaking that would go beyond the scope of this report. For example, fisheries may have long term effects on the ecosystem beyond what is discussed here and risk of accidental discharges from ship traffic and oil and gas activities may change considerably with increases in these activities. In addition, it should be acknowledged that our knowledge about future impact is limited. For example, until recently, ocean acidification was rarely considered an important factor, yet today it is considered a driver that may have profound effects on marine ecosystems.

As is known from previous reports (e.g. Loeng 2008), climate change may have considerable impact on the Barents Sea ecosystem. Some of these effects may already be visible in the ecosystem (see chapter 4.5). Effects may be large also from ocean acidification, but the uncertainty associated with this is much larger than for climate change effects. Fishery induced evolution may be responsible for a decreasing trend in onset of reproduction of cod that has been observed for several decades. If the trend is indeed an evolutionary response, it may continue and affect the reproductive potential in the cod stock and the role of cod as an important predator in the ecosystem. Climate change may cause increased input of pollution to the Barents Sea, and some signs of this may already be visible.

4.6.1 Future climate change and its effects on the ecosystem and human activities

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Air temperatures have increased almost twice as fast in the Arctic than the global average over the last 50 years. Models predict that air temperatures will continue to increase considerably, and summer sea ice in the Arctic will disappear before the middle of this century and winter sea ice by the end of the current century. 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 the ecosystem will be. However, it can be predicted with fair certainty that ice-associated fauna and flora will be lost, or 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.

In addition to the problems of understanding how the ecosystem will respond to varying degree of warming, there are large uncertainties associated with what the patterns of warming may actually be. For example, at the 2008 ICES workshop on cod and future climate change it was pointed out that many of the IPCC 2007 regional climate models downscaled from Global Circulation Models (GCMs) demonstrate large differences with observations on a regional basis. Also the Global Circulation Models (GCMs) are not able to reproduce well the two major modes of variability over the last century, the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO). Thus, the conclusion of the workshop was that the available global and regional climate models are not currently adequate for impact studies on the marine ecosystem. Without the development of regional climate model systems and the development of adequate downscaling strategies it is not possible to go on to implement coupled biological models of lower trophic level dynamics and its consequences for species at higth trophic level for the next 20–50 years. A considerable scientific effort will be required to design, initialize, run and test regional models which produce output that is relevant to impact studies. Until this is done the impact assessments will have to be based on "what if" scenarios.

Below, projections for future climate change are discussed first. Then, effects on biological components in the ecosystem are considered

4.6.1.1 Projections of future climate change

The IPCC Fourth Assessment Report (AR4) undertook an evaluation of the evidence for and impacts of anthropogenic change worldwide where they concluded that human-induced climate change was occurring (IPCC, 2007). As part of the IPCC process, the results from several Ocean-Atmosphere Global Circulation Models were presented. The performance of 20 models for different Arctic regions, including the Barents Sea, was evaluated by Overland and Wang (2007). Their assessment was based upon each model's ability to simulate observed seasonal changes in ice concentrations for the period 1979-1999. For the Barents Sea, a limit of within 30% was used to determine acceptable models and those exceeding 30% were considered unacceptable. The reasoning was that the models should be able to hindcast the present day conditions if they are to do a good job on future projections. Most of the models produced too much ice in the Barents, as only 7 models met the acceptable criteria. By 2050 using A1B scenario, 5 of these 7 models indicate a 40% or more loss of sea ice in the Barents Sea. The annual mean temperature in the Barents Sea at the end of the 21st century under the A1B scenarios based on the ensemble mean from all of the IPCC GMCs shows maximum temperature increase of around 7°C, but this is felt to be too high due to an overestimate of the albedo feedback caused by the removal of the present-day simulations' excessive sea-ice cover (IPCC, 2007).

The Bergen Climate Model (BCM) was not one of the 7 models that performed well in the IPCC evaluation but an earlier version of that model had produced more realistic ice coverage. Using the earlier version of the BCM, Furevik et al. (2002) developed future climate scenarios for the Barents Sea. By 2080, they suggested surface ocean temperatures will warm 1° to 2°C (Figure 4.6.1), winter sea ice will almost disappear, Atlantic waters will spread farther eastward and northward, and the surface mixed-layer depth will increase due to stronger winds. Climate scenarios obtained from the regional climate model REMO of the Max Planck Institute for Meteorology in Hamburg, Germany and forced by a global climate model driven by a B2 scenario suggested a 25% increase in freshwater runoff to the Barents Sea and the snow season was projected to be 30-50 days shorter, with the peak spring discharge occurring about 2-3 weeks earlier than in the present day but remaining dominated by snowmelt (Dankers and Middelkoop, 2008). In spite of this, model studies are predicting an increase in salinity due to higher salinities in the Atlantic Water inflows, generated by higher evaporation in the tropics (Betke et al., 2006). Modelling studies by Ellingsen et al. (2008) suggested that higher temperatures in this inflow resulted in the fraction of water in the Barents Sea with temperatures >1°C increased by 25% between 1995 and 2059 (the same magnitude as the present seasonal change) but with high interannual and multi-decadal variability. They also noted that sea-ice coverage will decrease with the largest decline during the summer resulting in virtually ice free conditions by 2059. Huse and Ellingsen (2008) examined changes in the position of the Polar Front that separates the cold Arctic and warm Atlantic waters. 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 will move farther north and east (Figure 4.6.2).

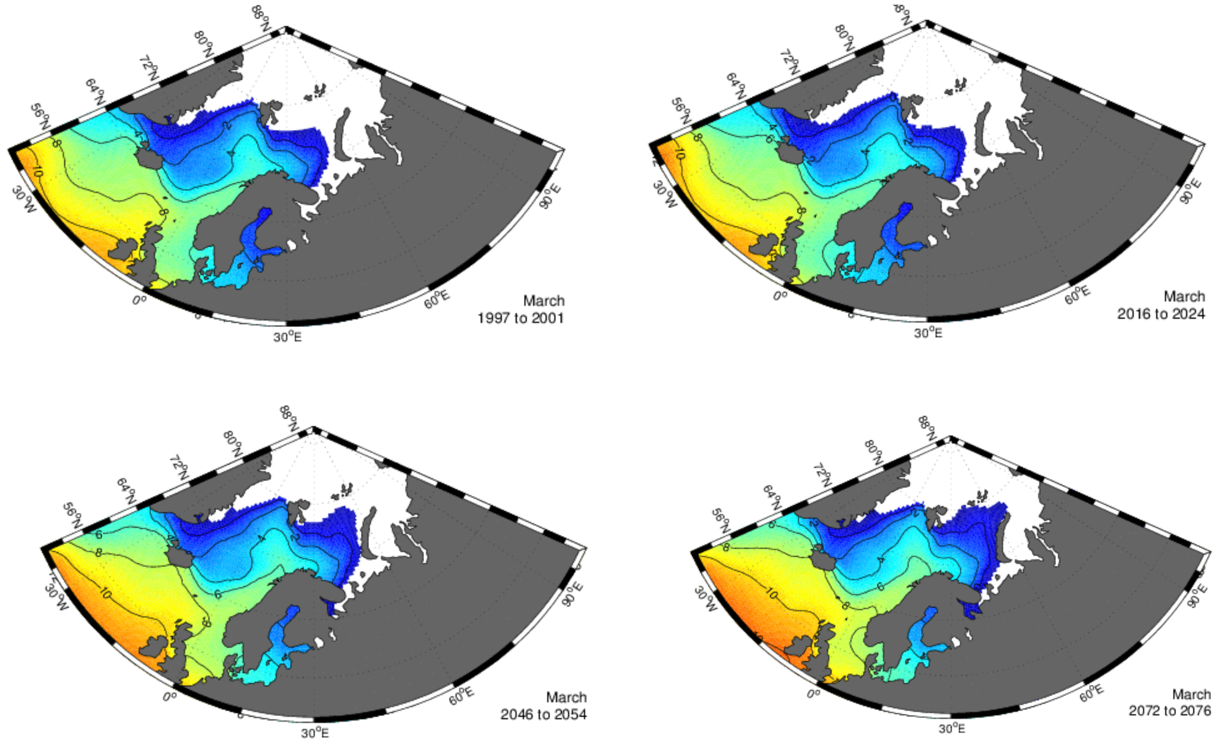

Figure 4.6.1. Historical and forecast sea surface temperatures and sea ice during March based on the Bergen Climate Model (taken from Furevik et al. 2002).

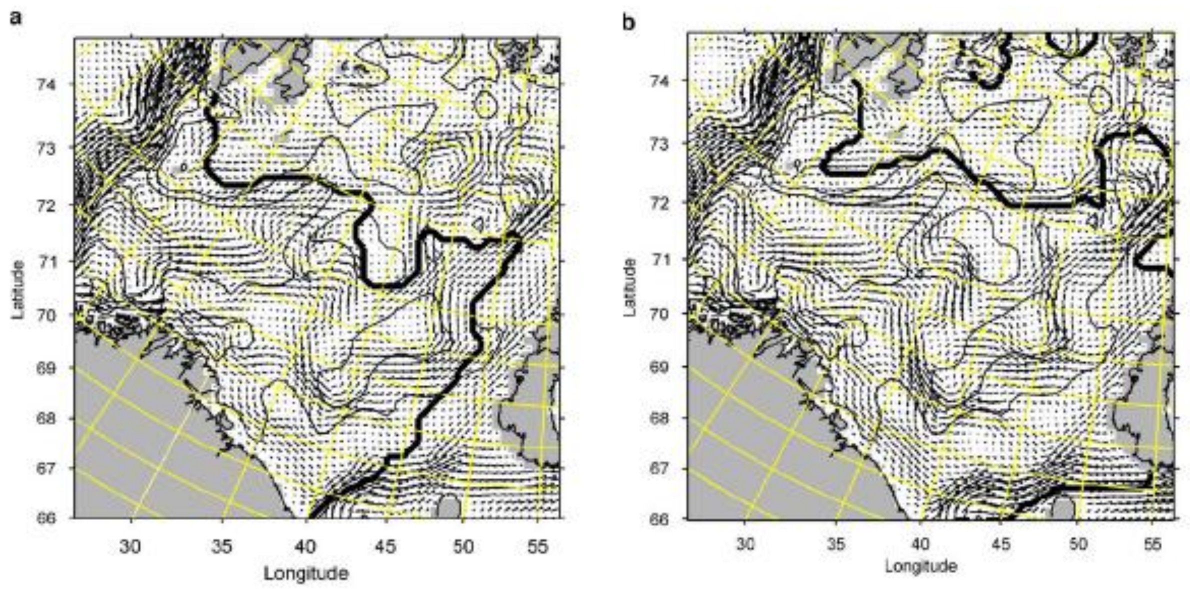

Figure 4.6.2. The modeled currents and the position of the Polar Front (bold line) for the Barents Sea during (a) 2000 and (b) 2047 (taken from Huse and Ellingsen, 2008).

Recently, Paul Budgell (IMR, personal communication) used the GISS Ocean-Atmosphere Model to downscale to a regional model of the Barents Sea based on ROMS (Regional Ocean Modeling System). The GISS OAM was chosen based on its selection by Overland and Wang (2007). Temperature results from ROMS for 1986-2000 (present) to 2051-2065 (future) for 0-50 m, 50-100 m, and >100 m to the bottom suggested increases in the sea temperatures throughout the Barents Sea were typically 1°C in both winter and summer. The largest increase occurred during summer with temperature increases of 2 to <4°C over the upper 50 m in the eastern (>30°E) and northern (>78°N) regions of the Barents Sea. In the 50-100 m layer, temperatures increased by the same amount but only in the eastern Barents Sea while in this same area in the layer from 100 m to the bottom, temperatures increased from 1° to <3°C. In winter, temperatures rose by 2 to 3°C but were restricted to the eastern region in the upper 50 m layer and about 1°C less in the layers below 50 m. While future projections of the summer distribution of ice indicated almost no ice left in the Barents Sea, there was still ice left in winter, including most of the northern region as well as a narrow band of ice immediately to the west of Novaya Zemlya. Comparison of ice concentrations with present conditions showed a decrease into the future with the largest changes in the eastern area of the Barents Sea and somewhat lower ice concentrations also in the north.

It must be cautioned that the atmospheric and ocean climate scenarios remain highly uncertain. Better regional models of the Barents through improved downscaling from the GCMs are required. There is a need to undertake the downscaling using several GCMs and then take an ensemble mean. This should provide a better estimate and 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 Budgell has not been attempted. In a coupled model the changes in the ocean feedback to the atmosphere and influence it. In an uncoupled model, there is no feedback.

4.6.1.2 Projections of ecosystem responses to climate change

Primary production and zooplankton

The disappearance of seasonal sea ice will result in increased primary production in the Barents Sea (Øiestad, 1990; Loeng et al. 2005, Ellingsen et al., 2008). The disappearance of seasonal sea ice would eliminate the ice-edge blooms, which would be replaced by blooms resembling those in the more productive Atlantic waters and their timing would be determined by the onset of seasonal stratification. Loeng et al. (2005) suggested the spring bloom would occur earlier and this would enhance annual primary production by extending the growing season. They also stated that regions where the seabed or the depth of mixing is <40 m are likely to favour diatom blooms, whereas if mixing extended to about 80 m it would likely favour *Phaeocystis*. Thus, projected stronger winds are likely to result in *Phaeocystis* becoming more common than at present in the northern and eastern regions of the Barents Sea. If the surface mixed layer extends beyond about 80 m, it is possible that a low-productive community dominated by nanoflagellates would be favoured. This would imply little transfer of carbon to herbivores and sediments because the grazers would be largely ciliates (Sakshaug and Walsh, 2000).

Ellingsen et al. (2008), using a coupled biological-physical model, found a slight (8%) increase in the mean level of phytoplankton production between 1995 and 2059, due principally to increases in the northern Barents. This is a result of a combination of higher light levels in areas of decreased ice extent and higher nutrient levels from the increased influence in the Atlantic waters. This compares to the 30% increase suggested earlier by Slagstad and Wassmann (1996) between heavy and light ice years.

One effect of climatic changes is changes in run-off from land, due to increased precipitation and melting. Such changes could have a large impact on the phytoplankton abundance, species composition, and production. An increase in the run-off could increase the amount of nutrients added to coastal water, leading to higher phytoplankton activity and changes in the stoichiometric environment (changes in the N:P:Si ratio). An increased run-off could also alter the light regime with more humic substances (DOM) and a stronger light attenuation as well as an increased degree of stratification. The outcome of such changes, on the species composition, could be either an increase in smaller flagellates and dinoflagellates due to low light and strong stratification or species that takes advantages of higher nutrient concentration (e.g. diatoms). It should also be noted that climate warming may act to reduce the supply rate of nutrients, because warming and increased input of sea ice melting can lead to increased stratification of the water column, thus reducing the mixing of nutrient rich deepwater with the layers higher in the water column where primary production occurs (Sakshaug and Slagstad 1992; Wassmann et al. 2006; Loeng and Drinkwater 2007; Tremblay and Gagnon 2008).

Loeng et al. (2005) noted the risk of a mismatch with zooplankton in the event of earlier phytoplankton blooms and the potential of less food supply to fish (Hansen et al., 1996). In such a case, vertically exported production and protozoan biomass are likely to increase. However, a match with phytoplankton blooms could be achieved by arctic copepods, such as *C. glacialis*, which can adjust its egg production to the development of the phytoplankton bloom, whether early or late in the season. The expected northward extension of warm water inflows would carry with it temperate zooplankton resulting in a northward shift in their distribution (Skjoldal et al., 1987) while ice fauna, such as the large amphipods would suffer massive loss of habitat because of the disappearance of multi-year ice (Loeng et al., 2005). Ellingsen et al. (2008) also predicted that the 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 increased abundance of Atlantic zooplankton is believed to be caused by higher transport into the Barents through inflow of warm Atlantic water (Stenevik and Sundby, 2007) and to faster turnover rates due to the higher temperatures (see Tittensor et al., 2003). Increased amounts of pelagic plankton eating fishes, such as blue whiting and mackerel may also trigger decreases in abundance of Atlantic zooplankton. In addition, it is uncertain how jellyfishes, an important group of predators on zooplankton, may respond to climate changes.

Arrigo et al. (2008) discussed the general topic of pelagic versus benthic production with the loss of sea ice. 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. However, if advection of increasingly warm surface waters is responsible for the early losses of sea ice, zooplankton growth may not be negatively impacted and carbon export may remain unchanged or even diminish. Furthermore, reduced sea-ice cover has been proposed to favour a pelagic-dominated ecosystem over the more typical coupled sea-ice algae and benthos ecosystem (Piepenburg, 2005). This ecosystem switch could reduce the vertical export of organic carbon and decrease pelagic-benthic coupling, despite overall increases in phytoplankton productivity. Thus what will happen in regards to pelagic-benthic coupling remains unclear.

Changes in fish production and distribution

If warming causes phytoplankton to increase, this is expected to result in an overall increase in fish production. For example, model studies show that higher primary production tends to lead to an increase in cod recruitment in the Barents Sea (Svendsen et al., 2007). Higher temperatures should also lead to improved growth rates of the fish and together with increased recruitment is expected to lead to increased fish yields (Drinkwater, 2005; Stenevik and Sundby, 2007). Increased overall production is expected to produce increased catches of cod, haddock and other species (ACIA, 2005). Cod are expected to spawn farther north and new spawning sites will likely be established (Sundby and Nakken, 2008; Drinkwater 2005).

Possible impacts on the capelin population were explored by Huse and Ellingsen (2008). The movement of the Polar Front farther north and east (Figure 2) will result in a shift in the adult capelin distribution towards the north-eastern Barents Sea, consistent with distributional changes under observed cold and warm years by Gjøsæter (1998). Capelin were also predicted to spawn earlier and to shift their spawning sites eastwards from their present position off northern Norway and establish new spawning locations along Novaya Zemlya (Huse and Ellingsen, 2008). Herring, blue whiting and possibly Atlantic mackerel will spread farther eastward resulting in new species interactions and potentially change the structure and function of the Barents Sea ecosystem (Stenevik and Sundby, 2007). For example, in chapter 4.5 of this report it is described how a larger herring stock even on a short term basis may have profound impact on the ecosystem by reducing biomass of zooplankton and severely affect recruitment of capelin. Indirectly, this may affect a number of species, including cod, seabirds and mammals. Salmon abundance likely will increase in Russian waters as previously observed under warmer conditions (Lajus et al. 2005) and also extend to northern Svalbard. The distribution shifts of fish will result in a higher proportion of the fish (such as cod and haddock) into Russian waters although because of expected increases in total production, the total number of fish in both the Norwegian and Russian economic zones should increase (Stenevik and Sundby, 2007). The extent that fish will expand farther east and north will depend not only upon changes in ocean conditions, but also upon the degree of future fishing intensity. Indeed, examining the effect of different management regimes on Norwegian cod fisheries in conjunction with climate change, Eide (2008) concluded that these management schemes will play a more significant role than climate change on the economic performance of the fishing industry in the Barents Sea.

Bioclimatic envelopes are a set of physical and biological conditions that are suitable to a given species and are generally identified from present associations. Cheung et al. (2008) determined the responses of Atlantic cod and capelin to climate change after 30 years using bioclimate envelope models that included sea temperatures, bathymetry, habitat and distance from sea ice. They found that for cod in the Barents Sea there would be an increase in overall abundance with a shift in distribution eastward and northward with a large increase in the Russian zone (Figure 4.6.3) similar to the projections made by Drinkwater (2005) and Stenevik and Sundby (2007). For the polar cod, Cheung et al. (2008) suggested the population would disappear from the Barents Sea after approximately 30 years.

Vikebø et al. (2007) examined the potential impact of a reduction in the thermohaline circulation (THC) in the North Atlantic on the larval drift of the North-east Arctic cod. This circulation pattern brings warm water north which cools, sinks and returns as a deep water current. Using a Regional Ocean Modelling Systems (ROMS), they imposed a 3 times present river discharge to the Nordic Seas and the Arctic Ocean greatly 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 a south and westward drift of cod year classes from the Barents onto the Norwegian and Svalbard shelves, a reduction in the numbers of pelagic juveniles that survive, and an increase in the proportion of larvae and juveniles advected along West Svalbard and possibly into the Arctic Ocean. These latter would not be expected to survive, however.

The results of long-term simulations by STOCOBAR model show that a temperature increase of 1-4C° in the Barents Sea will lead to acceleration of cod growth and maturation rates. This will positively affect the general production of the cod stock but on the other hand, cannibalism will also increase, which will have a negative effect on cod recruitment and the total cod abundance.

The summarized consequences of a temperature increase in the Barents Sea for the cod stock and catches are presented in Figure 4.6.4. The harvest control rule for cod in the simulations correspondents to the present management strategy, which is based at the precautionary approach. The cod yield for the all temperature scenarios were calculated using existing values of the biological references points for the cod stock.

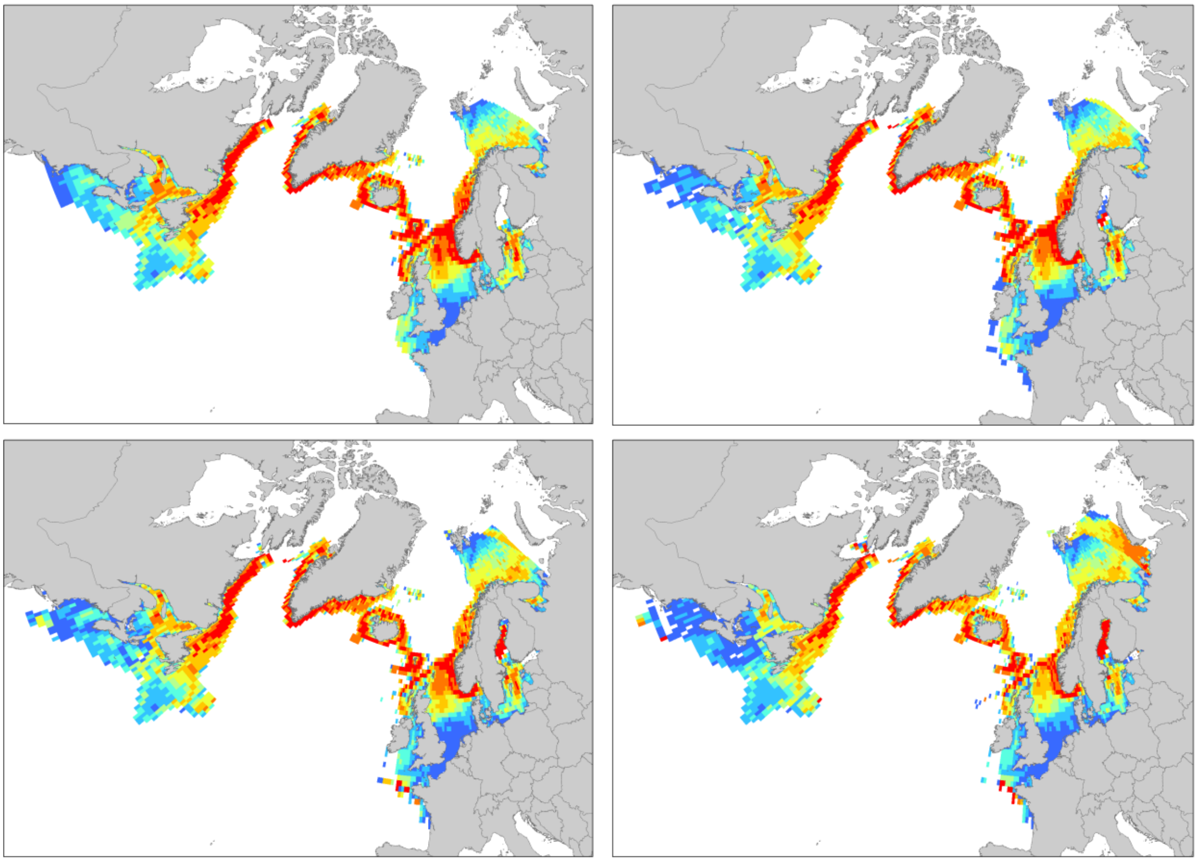

Figure 4.6.3. Simulated changes 60 year ahead in the distribution of Atlantic cod under ocean warming. Upper left panel is year 2000, upper right panel is year 2020, bottom left panel is year 2040 and bottom right panel is year 2060. (Updated simulations of Chueng et al, 2008, conducted in 2008 by the same group, printed with permission).

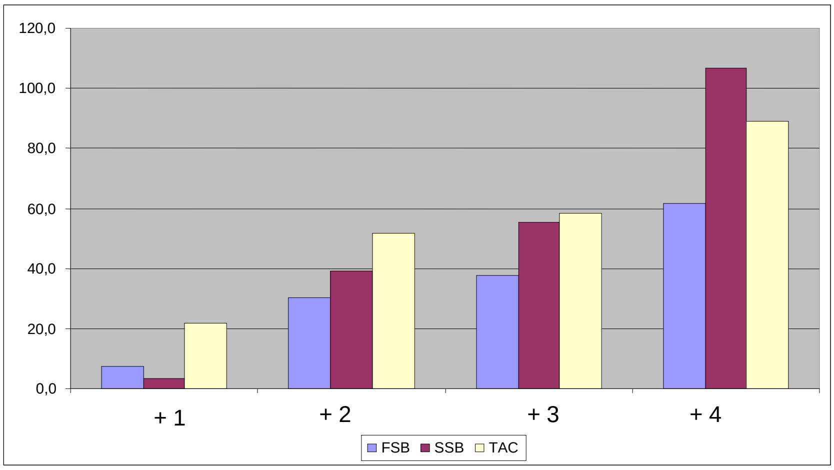

Figure 4.6.4. Relative changes (% to simulated values under the current temperature regime) of cod stock biomass and catches at temperature increase in the Barents Sea by 1-4 C° according to the STOCOBAR simulations. FSB – fishable stock biomass, SSB – spawning stock bimass, TAC – total allowable catch.

Benthos, cephalopods and shellfish

With increasing temperatures, temperate benthic species are expected to become more frequent and the species composition of the benthos will change. A shift in the benthic communities towards boreal species at the expense of Arctic species is expected, as observed in the early 20th Century warming (Blacker, 1957; Nesis, 1960). Such changes will affect benthic production (i.e. food for demersal fishes and other vertebrates) and may therefore have considerable management implications. In addition, the marginal ice zone is an area of high benthic productivity because of large amounts of ice algae from melting ice sinking to the bottom. If sea ice is lost or greatly reduced, this production pulse will be greatly reduced or disappear. Also, much of the production in these areas may shift from benthic to the pelagic species, resulting in dominance of pelagic species. However, there is considerable uncertainty associated with this (see section on primary production and zooplankton above).

Future fluctuations in zoobenthic communities will be related to the temperature tolerance of the animals and the future temperature of the seawater. Whereas a majority of the boreal forms have planktonic larvae that need a fairly long period to develop into maturity, arctic species do not (Thorson, 1950). Consequently, boreal species should be quick to spread with warm currents in periods with warming, whereas the more stenothermal arctic species will perish quickly. During periods of cooling, the arctic species, with their absence of pelagic stages, should slowly follow the receding warm waters. Boreal species that can survive in near-freezing water could continue to live in the cooler areas.

Marine mammals

Polar bears, ringed seals, bearded seals, harp seals and hooded seals are all dependent on sea ice. It is the primary foraging habitat for polar bears, and a resting and breeding habitat for all of these seals. Additionally, some of the seals feed on ice-associated prey. As a result of climate warming and the associated loss of sea ice, distribution and abundance of these species are expected to decrease in the Barents Sea. Some observations supporting this expectation have already been made. In the recent warm years in the Barents Sea, reproduction has been low in ringed seals and harp seals. Pup mortality of harp seals has also been high in the White Sea. No effects of declining sea ice have been detected for polar bears in the Barents Sea, but in areas of Canadian Arctic, reduced body condition and lowered rates of reproduction have been observed as a consequence of a longer ice-free season.

Three species of whales, beluga whales, narwhal and bowhead whales are associated with sea ice. However, the linkage between these species and sea ice is less well understood than for the other ice-associated marine mammals. Sea ice is thought to provide a predation shield, and may also serve to reduce competition for food. But, because of our lack of detailed ecological data on these species in the Barents Sea region it is hard to predict what will happen to these species in a warmer climate.

Several species of marine mammals are found only in the ice-free season and ice-free regions of the Barents Sea. Climate warmingis expected to result in these species spending longer periods of time in the Barents Sea and expanding their distribution north and eastwards. Observations supporting these predictions have already been made. An increasing number of fin whales have been observed to the north of Svalbard, and boreal species such as sei whales and harbour porpoises have been observed at very high latitudes in recent years. Killer whales also appear to be arriving in at high latitudes very early in the spring.

Seabirds

Seabirds that are dependent on sea ice may be affected directly by climate changes. ivory gulls, for example, which feed in the marginal ice zone or in openings in the ice, distribution and abundance is expected to decrease or the species may disappear totally from the Barents Sea. Similar responses can be expected for other species that are dependent on sea ice. Direct effects like reduced breeding success due to heavy rain- and snowfall early in the breeding season, might be an increasing problem if weather gets worse.

For other seabird species, climate change effects are more likely to occur indirectly through changes in distribution and abundance of prey species. This means that some species may be negatively affected. For example, little auks *Alle alle* feed on large energy rich Arctic zooplankton, which will be replaced by smaller and less energy rich Atlantic species in a warmer climate. This will probably cause abundance of little auks to decrease substantially throughout their current range in the Barents Sea.

Other species may be affected positively by climate warming if their food sources are positively affected. For example, if capelin shift to a more northern and easterly distribution, seabirds that are dependent on capelin may expand in these parts of the Barents Sea, and increase in the southern parts.

Infectious organisms

In general, climate warming will tend to cause infectious organisms to acquire a more northerly distribution. The response for each pathogen species will vary from no response to possible large responses. Thus, new species of infectious organisms will be established in the Barents Sea, but it is difficult to predict which ones.

Because infectious organisms may have profound effects on the dynamics of host populations and structure of ecosystem, this may affect the overall dynamics of the ecosystem in Barents Sea.

Overall impact on the ecosystem

To understand the overall effect of climate change on the ecosystem in the Barents Sea, it is necessary to look across different groups of organisms and take into account how species interact and influence each other in the ecosystem. As described above, there is considerable uncertainty associated with how individual groups of organisms will respond. For example, based on our current understanding, we cannot predict whether abundance of a central group like zooplankton will increase or decrease in a warmer Barents Sea. This uncertainty does not get smaller when we attempt to put together a broader picture and take into account the many complex ways species may interact in the ecosystem. Therefore, it is impossible to predict in detail how the ecosystem will respond to climate warming.

A more useful approach can therefore be to analyse different types of changes. It is possible to distinguish between two types of ecosystem responses to climate warming. One type is ecosystem shifts, in which basic parts of the structure of the ecosystem is changed irreversibly. Such changes can have large effects on biodiversity and productivity of the system. An example is the changes that have occurred in the Northwest Atlantic, where crustaceans have taken over as dominating group after collapses of cod and other large predatory fishes. The other main type of change can be termed smaller changes. Here, the main groups in the ecosystem will remain the same, although species composition may change.

As described above, we can predict with fair certainty that a number of such smaller changes will occur as a result of climate warming. In particular it can be predicted with fair certainty that southern (boreal) species will become more northerly distributed and enter the Barents Sea. Ice dependent species will likely decline or disappear. Thus, species composition will change considerably. In addition, several of the species that are present in the Barents Sea today may shift to a more north-easterly distribution and/or change in abundance.

Such small changes may spread to other species in the ecosystem. For example, Norwegian spring spawning herring tends to produce strong year classes in warm years. Strong year classes of herring can have strong negative effects on capelin and have caused the capelin stock to collapse three times since the mid 1980s. As described in chapter 2.6.4, this has had large effects on other species in the ecosystem, including zooplankton, cod, seabirds and marine mammals. If a warmer climate causes herring to produce strong year classes more often, negative effects on capelin may become more persistent, with potentially considerable consequences for the ecosystem (this is discussed in more detail in chapter 4.5).

It is possible to draw up a scenario where such changes and other smaller changes get so numerous that they can no longer be absorbed by the existing structure in the ecosystem. If so, the ecosystem may shift irreversibly to another state. Climate change has contributed to such large shifts in other marine ecosystems, but most often as a factor in combination with other types of impact, such as fisheries and pollution. It is therefore reasonable to assume that the probability of climate induced regime shifts in the Barents Sea will increase with increasing pressure from other factors such as fisheries, which has a large impact on the ecosystem today. Another important factor to consider is acidification. As described below, acidification can cause considerable changes in the ecosystem and thus potentially amplify the effects of climate change on the ecosystem.

4.6.2 Possible effects of ocean acidification

Y. Børsheim (IMR), P. Arneberg (NPI), E.E. Syvertsen (SFT)

Emissions of CO_2 from the burning of fossil fuels have increased with more than 1200 % over the last 100 years. Increasing levels of CO_2 in the atmosphere do not only contribute to warmer climate, but CO_2 is also taken up by the oceans and changes their chemistry. The oceans have absorbed approximately 50% (ca. 525 billion tons) of the carbon dioxide (CO_2) released to the atmosphere since the beginning of the industrial revolution. When carbon dioxide is absorbed by the oceans it reacts with seawater to form carbonic acid. This has caused an increase in the acidity of about 30% (reduction in pH by about 0,1 units). Present changes are at least 100 times more rapid than similar changes experienced over the past 100 000 years. Data on CO_2 in the atmosphere and expected emissions makes it possible to model ocean acidification with a high degree of certainty. By 2100 the reductions are predicted to be in the order of 0,2-0,3 pH units (e.g Orr et al. 2009, Figure 4.6.5).

Changes in ocean carbon chemistry due to elevated atmospheric CO_2 are not only restricted to a reduction in pH but also result in decreased concentration of carbonate ions. This means that it will become gradually more difficult for marine organisms to build calcium carbonate shells and skeletons. As outlined below, acidification will also have other effects on biota. Impacts of ocean acidification on biological processes are therefore expected, but their exact nature remains largely unknown and may occur across the range of ecosystem processes. A discussion of possible effects is given below. This is largely based on Fernand et al. (2007).

Research impact of changes in pH into water column processes has primarily focused on those organisms that calcify. This group includes coccolithophorids, and foraminifera (both are phytoplankton) and pteropods (a type of planktonic snails). In the Barents Sea, pteropods that calcify are a significant food source for herring. Herring are an important part of the ecosystem and a significant food source for other fish such as cod, for marine mammals, and for seabirds. As the saturation of aragonite (which constitutes most of the shell) falls below 1, the shell will corrode.

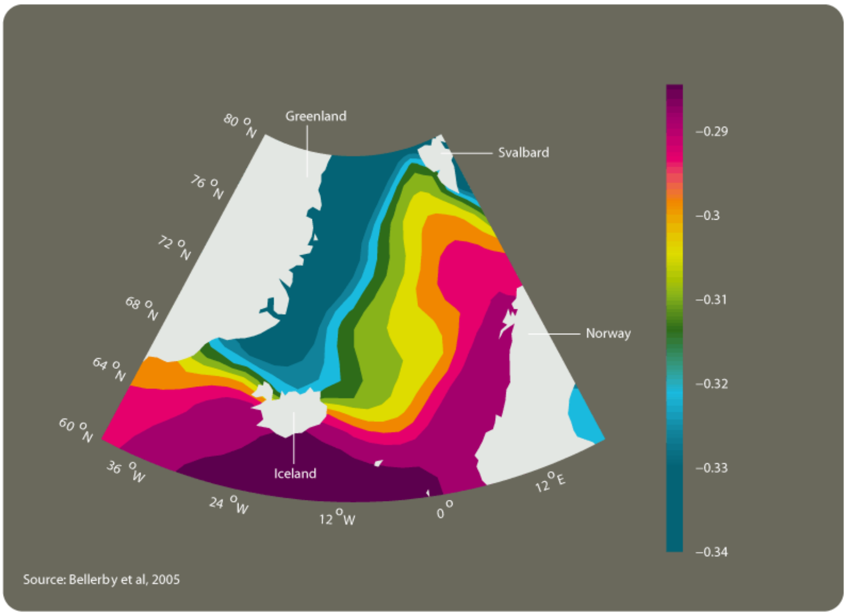

Figure 4.6.5. Predictions for change in the pH at the ocean surface toward 2100. Source: Bellerby et al. 2005.

The absorption of CO_2 generally is faster in colder water and thus may rapidly affect the Barents Sea and northern waters. There are limited data available from Barents Sea, but in the Norwegian Sea there is already a measurable decrease in the deep water pH. Also in Swedish waters a decrease in pH is reported (Andersson et al 2008). Research from the Southern Ocean indicates that parts of that area may become corrosive to the calcified shells and skeletons of many organisms by 2030 (Orr et al. 2009). Acidification will vary through the year and from place to place, but substantial and unforeseeable effects on the ecosystems may be expected within a generation in most areas.

As mentioned above, acidification can affect biota through reduced calcification and other effects. The full range of effects on benthic organisms includes:

- Respiratory stress (reduced pH limits oxygen binding and transport by respiratory proteins, and leads to reduced aerobic capacity);
- Acidosis (reduced internal pH, disruption of acid – base balance impairs function and requires energy to restore or maintain optimal internal pH levels);
- Reduced calcification (depression in the carbonate saturation state increases the difficulty of carbonate deposition, with unknown etabolic consequences);
- Metabolic depression (torpor, elevated CO2, reduced pH, or both can cause some animals to enter a state of reduced metabolic rate and semi ‑ hibernation).

Sea urchins are highly vulnerable because there is no impermeable membrane to isolate it from the surrounding water. Considering corals, experimental studies on tropical shallow corals have demonstrated that biogenic calcification depends on the concentration of available carbonate ions; the lower the pH of seawater, the lower the amount of carbonate available and the lower the rate of calcification by corals. Other work (Gattuso et al., 1999) demonstrates the importance of additional factors, such as irradiance and nutrient stress, in determining calcification rates. These parameters, along with temperature, are likely to interact with pH in the future climate, and indeed their interaction requires further analysis. The North Atlantic is home to extensive coral reef frameworks built by cold water corals. As the response of coldwater corals to pH is expected to be similar to that described above for tropical corals, concern for this highly diverse and yet little explored ecosystems of the deep sea is mounting (Roberts et al., 2006).

Acidification is likely to have some direct and indirect impacts on fish and fisheries. The nature and degree of such impacts is currently unknown but should be considered against a backdrop of considerable historical overfishing (Jennings and Blanchard, 2004; Piet and Rice, 2004; Dulvy et al., 2005). The direct effects on fish and fisheries may be relatively limited. Fish early life stages, such as eggs and larvae, are more sensitive to pH than adults (Ishimatsu et al., 2004). However, mortality at the early life stages of broadcast spawning species is typically great and highly variable, owing to natural match – mismatch and density dependent processes in the planktonic stages (Hjort, 1914; Cushing, 1990; Goodwin et al., 2006). Indirect effects are likely to be more relevant but even harder to quantify. Ocean acidification may influence the structure and productivity of primary and secondary benthic production which, in turn, may indirectly affect the productivity of fish communities and higher trophic levels. Changes in food source, e.g. Barents Sea herring feeding on sea butterflies (pteropods), may result in shifts in species distribution, lower species abundance, or diet shifts. The degree and nature of adaptation will strongly influence their availability to fisheries and their productivity. The possible effects of acidification on the timing of appearance, abundance, and quality of larval fish prey sources, such as phyto and zooplankton, remain unknown

(Edwards and Richardson, 2004). The gaps in knowledge that require addressing are extensive but could focus on key target fish species, particularly those that depend heavily on calcifying taxa as prey, e.g. pteropods. A key unknown is the relative importance of acidification for fisheries.

Acidification effects have yet to be observed in shelf seas. Therefore, the effects that acidification has had so far are likely to be minor relative to the comparatively massive impacts of overexploitation of fisheries during the last few decades. Long term effects of acidification may however be substantial, as discussed in the text above.

4.6.3 Evolutionary effect of fishing on maturity in cod

P. Arneberg (NPI), A. Filin (PINRO) K. Enberg (University of Bergen), C. Jørgensen (University of Bergen)

Age at first reproduction has declined markedly in cod the last decades (Figure 4.6.6). This may have considerable consequences for cod recruitment and the role of cod as a top predator in the ecosystem. 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.

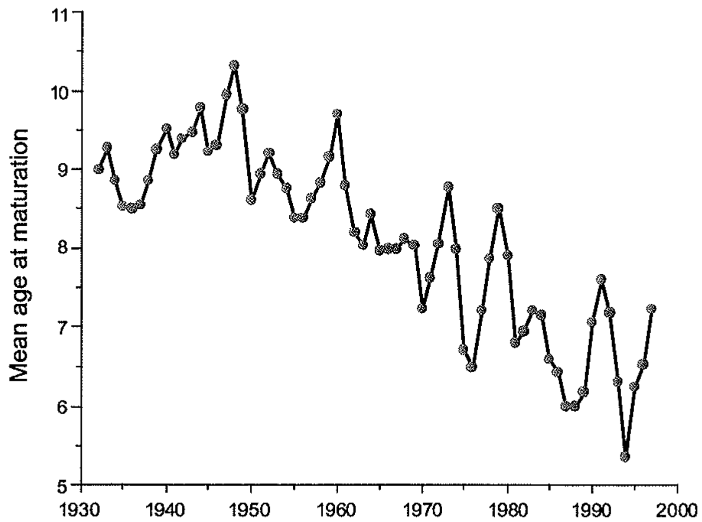

Figure 4.6.6. Development in mean age at maturity (years) in Northeast Arctic cod through time.

Re-reading of old cod-otholits suggests that age had been over estimated in the beginning of the time series in the above figure, and that the decline in age at maturity therefore has been less pronounced than suggested here (Zuykova et al 2009).

The possible explanation for the phenomenon is that 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 (e.g. Law and Grey, 1989). The following illustrates the mechanisms involved. Because the number of offspring that a cod can produce increases considerably with body size, older fish generally produce more offspring than young fish. Before 1930, fisheries were almost exclusively on the coastal spawning grounds and fishing mortality was considerable here. In the nursery areas in the Barents Sea, fishing mortality was negligible. In this situation, the cod that produced the most offspring through their life time were those that stayed for a long time on the nursery grounds before entering the spawning grounds, as they enjoyed the advantage of growing large in an area protected from fishing mortality. With the introduction of industrial fisheries in the nursery areas in the Barents Sea from the 1930s and onwards, the rules of this game have been turned upside down. The high fishing mortality in these areas today means that there is very little chance that a cod will survive to the age of 10 years. Those that get to reproduce, and make up the basis for the stock in the future, are those that spawn early. The "maturation at old age genes" are slowly removed from the stock.

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. Because eggs spawned by older cod are more viable than those from younger cod the reproduction potential of the stock has been negatively affected by the development (see Sundby 2000 for references). 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). Note that these effects will happen also because fishing reduces the age structure in the population, but any evolutionary effects may exacerbate such an effect and make it last longer if fishing pressure were reduced.

Fishing is also expected to lead to larger gonads for fish of a given size, or higher reproductive investment in general (Dunlop et al. in press, Enberg et al. 2009; changes reported for North Sea cod in Yoneda and Wright 2004). Over time, such evolution of maturation age and reproductive investment may lead to a larger proportion of the total biomass becoming sexually mature (Enberg et al. 2009). A consequence is that the stock may become more resilient to fishing, and stocks that have not undergone such life history evolution might be more prone to collapse under high harvest rates (Enberg et al., 2009).
If the adult cod generally becomes smaller because of maturing earlier, its role as top predator may change because smaller cod might eat a different composition of prey species than large cod. This might change the way cod affects its prey species, and have significant overall effects on the ecosystem.

In addition, the changes in body size that follows with evolutionary changes in age at maturity may affect spawning migrations. In a theoretical model the observed change towards maturation at earlier age and smaller size is likely to also shorten the southward spawning migration, such that the cod will spawn on more northerly locations (Jørgensen et al. 2008). The reason for this is that even though spawning in southern locations seems to be beneficial for the larvae because they will spend a longer time in warmer water as they drift towards the Barents Sea (Opdal et al. 2008), the southwards migration against the current is energetically costly, and smaller spawners do not have the energy reserves required for it. This might have consequences for the geographical allocation of fishing effort.

Models suggest that fishery induced changes in age at maturity may be very slow to reverse (Law and Grey 1989). Thus, parts of the changes may already be very hard to reverse, and this may become even more difficult as the current fishing practice continues.Different types of fishing gear remove different individuals. For example, gillnets select fish of a certain girth, whereas small fish may slip through the mesh and large fish may not get caught. This is different from a trawl, where sorting grids allow small fish to escape but most larger fish are caught. A model for Northeast Arctic cod suggests that trawling may lead to evolution towards early maturation even at low fishing intensities, whereas fishing with gillnets can take place at moderate rates without such evolution to occur (Jørgensen et al. 2009). Hutchings (2009) reached similar conclusions. These models used only gear selection based on body length, and although certain gear may also select hungry fish (Philipp et al. 2009) or fish of a different girth, but evolutionary effects of such harvesting has not yet been investigated theoretically. Gillnets that allow old and large fish to escape can also be beneficial for recruitment to the population if maternal effects make offspring from older mothers more viable (Law 2007, Venturelli et al. 2009).

4.6.4 Effects of climate change on pollution

C. D. Olseng (SFT), R. Kluge (SFT), A. Nalbandyan (NRPA)

Climate change may have consequences for the pollution situation in the Barents Sea. The routes and mechanisms by which persistent organic pollutants, heavy metals and radionucleides are delivered to the area are strongly influenced by climate variability and global climate change. Increased precipitation could cause faster washing out of hazardous substances that are currently combined in the environment. Increased sea temperature may indirectly influence the ecosystem through change in supply, turnover and effects of nutrient salts and hazardous substances. Change in wind patterns and sea currents may affect the transport of both local and long-range transboundary pollution. This can in turn enhance the already negative effects of hazardous substances. Melting of sea ice may release polluting substances trapped in the ice, but the knowledge about this is limited. More knowledge is needed about the combined effects of pollution, climate change, acidification and other impacts.

The role that climate change may play with regard to increased risk of radioactive pollution in the region is a developing issue. Changes in permafrost, precipitation and extreme weather events may affect infrastructure related to nuclear activities and will require new assessments. For example, the impact of weather and climate on infrastructure is well known for Andreeva Bay where freeze-thaw actions contributed to loss of integrity of the fuel storage facility and extensive contamination of Andreev Bay site. Further degradation combined with precipitation has contributed to radioactive material being washed out into the marine environment (AMAP, 2009). 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 both into an out of the Barents Sea may become more rapid than today (AMAP, 2009).

Climate change could also influence the transport of radionuclides from Mayak to the Arctic areas.

There is also a new potential risk of radionuclides' remobilization from localised areas with contaminated sediments, their re-suspension and transfer to the surrounding areas. In connection with the Barents Sea, it could be suggested to carry out additional monitoring in Chernaya Bay area (a fjord on the southwestern coast of Novaya Zemlya with high levels of radioactivity in sediments after nuclear tests during the Cold War). As known, the levels of $^{239,240}Pu$ in sediments from Chernaya Bay are among the highest ever reported for the marine environment and previous investigations indicated that the natural transport of contaminated sediments from Chernaya Bay has resulted in increased $^{239,240}Pu$ levels in the south-eastern part of the Barents Sea. In addition, elevated levels of radioactive plutonium measured in benthic biota indicate that significant uptake has occurred in the food chain (Smith et al., 1999; Carroll, 2002; Matishov, 2004). This could also represent a potential radiological threat to the local commercial fishery. Consequently there is a need to assess current status and potential environmental risk as well as to conduct more research to understand how the climate change will affect the inflow of new sediments and re-suspension and transfer of contaminated sediments to surrounding areas and potential long-term effects.

Changes in temperature may also lead to changes in turnover rates of radionuclides in cold-blooded animals such as fish. More research is needed to study relationships between diverse climatic, physicochemical and biotic factors that influence the uptake and bioaccumulation of radionuclides by marine species and to assess their combined effects.

5 Issues of importance for ecosystem based management

P. Arneberg (NPI), O. Titov (PINRO), O. Korneev (Sevmorgeo) and J.E. Stiansen (IMR)

As described in the introduction (chapter 1), this report will be used as a basis for developing ecosystem based management in the Barents Sea. The report is intended to establish the status for the entire Barents Sea ecosystem. It forms an information basis for establishing a management plan for the Russian part of the ecosystem and provide support for further developing the ecosystem based management plan for Norwegian waters in the area (The Royal Norwegian Ministry of the Environment 2005-2006).

Here, we discuss examples of issues that should be focused in a management plan for the Barents Sea. A short description of some of the principles of the management plan established on the Norwegian side is given first. Then, it is described shortly what types of issues that will be discussed in this chapter. The issues themselves are described in details in the subchapters 5.1 - 5.5, each dealing with one or a few of the types of human activities that takes place in the Barents Sea. In subchapter 5.6 an overall discussion is given.

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The purpose of the Norwegian management plan is to provide a framework for the sustainable use of natural resources and goods derived from the Barents Sea-Lofoten area and at the same time maintain the structure, function and productivity of the area's ecosystems. A central principle in the plan is that a set of goals for the environment is set up. Some examples of goals are:

Management of the Barents Sea–Lofoten area will ensure that diversity at ecosystem, habitat, species and genetic levels, and the productivity of ecosystems, are maintained. Human activity in the area will not damage the structure, functioning, productivity or dynamics of ecosystems.

Releases and inputs of pollutants to the Barents Sea–Lofoten area will not result in injury to health or damage the productivity of the natural environment and its capacity for self-renewal. Activities in the area will not result in higher levels of pollutants.

These goals are evaluated yearly, and an important part of the following up of the plan is therefore to gather the information necessary to assess to which extent the goals are met. In this process, emphasis is also put on identifying gaps in knowledge about the ecosystem and how it is influenced by human activities.

Typically, a goal is not met if human activities have impact on components of the ecosystem or there is a significant risk of such impact in the future. In addition, some goals may fail to be met even if there is no impact on the ecosystem. For example, the latter of the two goals listed above is not met if there are elevated levels of pollutants in the Barents Sea, even if these pollutants do not have any effects on species in the ecosystem. In this chapter, the following types of themes will be discussed as issues to be considered for the development of ecosystem based management:

- Instances where **impact** of human activities on the ecosystem has been demonstrated or is likely,
- Instances where there is a **risk** for such impact from future activities,
- Instances where there is no significant impact in the ecosystem but it has been shown or might be expected that the situation deviates from **goals** that we can expect that an ecosystem based management plan will have.

Although the highlighted themes are core issues for ecosystem-based management in the Barents Sea, it should be emphasized that no attempt is made to give a complete list of relevant themes. Rather, in the following subchapters, examples of potentially important issues are described for each type of human activities. Gaps in knowledge will also be discussed. Also here, no attempt is made to give a complete list of knowledge gaps but rather highlight some important ones. It should also be noted that the effects of climate change is not listed as a theme here. This is because this theme is typically dealt with in other management processes than ecosystem based management plans.

5.1 Fisheries

I. Røttingen (IMR), K. V. Drevetnyak, (PINRO), A. Filin, (PINRO), C. Kvamme (IMR), K. Nedreaas (IMR)

Fisheries and other harvesting is, together with climate change, the anthropogenic driver with the largest impact on the Barents Sea ecosystem. These activities have a long history in the Barents Sea, dating back to the early 17th century, when large scale whaling activity started. In the next centuries, whaling and other hunting led to the near extinction of several whale stocks and other marine mammals. Open ocean fisheries in the Barents Sea started in the beginning of the 20th century with the development of trawling technology. At present there is a multinational fishery operating in the Barents Sea using different fishing gears (trawl, longline, purse seine) and targeting several species (cod, haddock, Greenland halibut, capelin, shrimp). The largest commercially exploited fish stocks (Northeast Arctic cod, haddock and saithe) are now harvested within sustainable limits and have full reproductive capacity. However, some of the smaller stocks (golden redfish, beaked redfish and coastal cod) are overfished, and damage to benthic organisms and habitats from trawling has been documented. Overcoming these problems and further developing our understanding of the effects of fisheries in an ecosystem context are important challenges for management.

5.1.1 Management

Until the 1960ies there were few fisheries regulations outside the national fishery borders. In later years, and especially after the introduction of exclusive economical zones (EEZ), a series of catch and technical regulations has been introduced in order to increase the sustainability and long term yield. Important elements of fisheries management in the Barents Sea are the scientific advice given by International Council for the Exploration of the Sea (ICES). The Joint Russian-Norwegian Fisheries Commission (JRNFC) uses this advice to set the quotas.

5.1.2 Joint Russian-Norwegian Management of the fisheries in the Barents Sea

The stocks that form the basis for the fisheries in the Barents Sea are shared stocks between Russia and Norway. The management body regarding fisheries in the Barents Sea is the JRNFC. This commission was formally established in 1975. The competence of the Commission includes decisions on management strategies, quota allocation and technical properties of the fishing gears. JRNFC has also the competence to implement control systems to ensure the decisions made by the commission are followed by the fishing industry. The JRNFC thus decides on the total annual catch (TAC) and on allocation of the TAC to Russia and Norway. It also decides on catch quotas to third parties (non-coastal states).

After the size and allocation of the TAC is decided by the JRNFC, the national management bodies (Federal bureau of Fisheries in Russia, Ministry of Fisheries and Coastal Affairs and Directorate of Fisheries in Norway) divide the national quota on fleet groups, vessel quota, gears to be utilized etc.

5.1.3 Scientific advice

The basis for the scientific advice on utilizing the commercial fish stocks in the Barents Sea is a co-operation between Russian and Norwegian scientists. The scope of this work is defined in Appendix 10 in the Protocol from the annual meetings of the JRNFC. The scientists carry out joint surveys and other types of data collection. The data are analyzed within the auspices of ICES. Thus ICES gives the formal catch recommendations for the stocks in the Barents Sea. The management advice produced by ICES is in accordance with the principle of precautionary approach to fisheries given in UNCLOSE and FAO Code of Conduct for fisheries.

5.1.4 Control on compliance of the fishing fleet to regulations

There is at present, on the basis of decisions made by JRNFC, a co-operation between inspectors from the coast guard and other control authorities regarding inspection of fishing vessels and their fishing gears. There is also an ongoing work on harmonizing the technical measures of the fishing gear used by Russian and Norwegian fishing vessels. Further, there is a cooperation regarding a wide range of other measures such as satellite tracking of fishing vessel, control of the landing of fish products etc. There has been focus on the work to solve the problems of IUU fishing and trans-shipment in the Barents Sea area. An important field is to find measures to reduce discards of catches.

5.1.4.1 Control of the implementation of the decisions taken by JNRFC

The Accounts Chamber of the Russian Federation and the Office of the Auditor General of Norway in 2006-2007 conducted a parallel audit of the Management and Control of Fish Resources in the Barents Sea and the Norwegian Sea. The 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.

The audit topics were:

- 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

On the basis of the two parallel investigations, a joint memorandum was signed by the Auditors General of the two countries on 18 June 2007. The memorandum presents the common assessments and sums up the national results

5.1.5 Ecosystem considerations

Within fisheries, the ecosystem approach to management is a principle ascribed to, and adopted, by many governments, international organisations and agreements (Bianchi and Skjoldal 2008).

The current and expected state of the Barents Sea ecosystem and implementation of ecosystem considerations into stock assessments and to the fishery management in the Barents Sea has been considered routinely by the ICES Arctic Fisheries Working Group (AFWG) since 2002. The main aim is to include data on environmental and trophic interactions into management advice. Some ecosystem considerations are included in the estimation of catch quotas. For instance, the consumption of capelin by cod is considered before the catch quota for capelin is estimated.

5.1.6 Themes to consider when developing ecosystem based management

Although the largest commercial stocks are exploited sustainably, some of the smaller stocks are over-fished (chapter 4.4.1). In addition, bottom trawling may have considerable effects on benthic organisms and habitats (chapters 2.4.4, 2.6.3, 4.4.1 and 4.4.3). These conclusions are consistent with those made by the ICES Arctic Fisheries Working Group, which lists the following impact of the Barents Sea fisheries on the ecosystem:

- The demersal fisheries are mixed, and currently have largest effect on coastal cod and redfish due to the poor condition of these stocks.
- The pelagic fisheries are less mixed, and are weakly linked to the demersal fisheries (however, by-catches of young pelagic stages of demersal species have been reported in some pelagic fisheries).
- Trawling has largest effect on hard bottom habitats; whereas the effects on other habitats are not clear and consistent.
- Fishery induced mortality (lost gillnets, contact with active fishing gears, etc.) on fish is a potential problem, but not quantified at present.

In addition, this report has described how information on ecosystem interactions can be important for sustainable fishery management (chapter 4.5). Therefore, the following themes are considered as important for the development of ecosystem based management:

- Mixed fisheries, undersized fish, discard, bycatches and IUU fishing
- Impact of bottom trawling on benthos
- Implementing the ecosystem approach to fisheries.

In addition, the fishing fleet represents the largest number of ship movements in the Barents Sea and has a potentially negative impact on the ecosystem through emission of greenhouse gases. However, compared to the general maritime activity, the fishing fleet uses lighter diesel fuel and does not carry oil or hydrocarbons in the hold, thus having less potential for pollution if accidents occur. This aspect of the fisheries is therefore not discussed here.

5.1.6.1 Mixed fisheries, undersized fish, discard, bycatches and IUU fishing

The demersal fisheries are mixed, especially regarding cod and haddock. Usually the vessels are given specific quotas on cod and haddock. Even though discarding is illegal, when the quota of one of the species is taken there may be discarding of this species until the quota of the other species is taken.

The fisheries are regulated by minimum length and mesh size. At present there are different national regulations in Russia and Norway. However, there is now an ongoing work on harmonizing minimum length and mesh size used by Russian and Norwegian fishing vessels.
Bycatches of other species occur, especially redfish and, in the Norwegian cod fishery, coastal cod. These stocks are in poor condition and the bycatch may therefore have an important impact on the stock development. In the Norwegian cod fishery, several measures have been introduced to avoid bycatch of coastal cod, such as time and area closures, gear restrictions in coastal and fjord areas (use of trawl or Danish seine prohibited).

There are some reports of bycatches of marine mammals and seabirds in fishing nets. Further, seabirds have been taken as bycatch in the longline fishery. Devises for scaring away the birds when setting the longline have been developed and taken into use. This type of fisheries made impact on the ecosystem has not been quantified.

In general, there are many regulations and restrictions imposed by Russia and Norway in the fishery in order to reduce the negative impact of the fisheries in the Barents Sea. In order to make these regulations relevant, however, a strong and efficient control system must exist, both at sea and also when the catches are landed. This is imperative for reducing the impact on the ecosystem of the above mentioned elements.

5.1.6.2 Impact of bottom trawling on benthos

To conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. In general, the response of benthic organisms to disturbance differs with substrate, depth, gear, and type of organism. Seabed characteristics of the Barents Sea are scarcely known and the lack of high-resolution maps of benthic habitats and biota is currently the most serious impediment to effective protection of vulnerable habitats from fishing activities. An assessment of fishing intensity on fine spatial scale is critically important in evaluating the overall impact of fishing gear on different habitats and may be achieved, for example, by satellite tracking of fishing vessels. The challenge for management is to determine levels of fishing that are sustainable and not degradable for benthic habitats in the long run.

The quantitative effects of trawling have been studied to some degree. The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. Barents Sea hard bottom substrata, with associated attached large epifauna should therefore in particular be identified, but also the large soft sea bottoms covered by motile long lived epibenthos.

5.1.6.3 Implementing the ecosystem approach to fisheries

In addition to the work done through ICES, a joint IMR/PINRO study on development of ecosystem approach to the fisheries management in the Barents Sea is conducted at the request from the JRNFC. In 2003 the JRNFC requested IMR and PINRO to evaluate the prospects for long-term yield of commercial species in the Barents Sea, taking into account species interactions and the influence from the environment (chapter 4.5). According to this request a joint IMR/PINRO project on evaluation of optimal long-term harvest in the Barents Sea Ecosystem was initiated (Filin and Tjelmeland 2005). This work is ongoing and it is planned that the results will be implemented in the harvest control rules and technical measures which form the basis for the regulations of the Barents Sea fisheries.

Ecosystem information ought to play an important role in the design of fishery management strategies. We can use this information to exploit a stock either more efficiently or more carefully, according to the prevailing environmental conditions. Management of fisheries is always based on decision making under uncertainty. Incorporating data on ocean climate, lower trophic level bio-production as well as species interactions on higher trophic levels in catch recommendations for target species should reduce the uncertainty in scientific recommendations for sustainable harvest levels.

Management procedures should be robust to environmental variability as well as to changes in multi-species interactions (due to e.g. changes in the stock level of predators and prey for the stock in question). Management procedures estimated to be optimal (or precautionary) from observations taken over several ecosystem regimes may not be so for a given regime. The feasibility of a transition from constant biological reference points and harvesting control rules to reference points and rules, which depend on the ecosystem regime, should be explored. Trends and shifts in the environment are difficult to predict and occur on time scales of various lengths. If there is no basis for predicting ecosystem state, management strategies should be based on scenario testing using relevant linked fish-ecosystem models. Although adapting management procedures to changing environmental regimes is an interesting approach, it is difficult to imagine this being of much practical use in near future, at least not for long-lived species.

Simulations should use a stochastic approach to ensure that the resulting management recommendations are sufficiently robust. Taking into account uncertainties, the probability of undesirable consequences for the stock (e.g. stock level falling below the established threshold level) for a given harvest strategy can be estimated. Alternatively, future scenarios could be used to evaluate future risks for management.

5.1.7 Knowledge gaps

In order to impose regulations that effectively reduces the impact of the fisheries on the Barents Sea ecosystem, knowledge in many different fields is necessary; especially quantitative knowledge is lacking.

General knowledge gaps include:

- Mapping of bottom habitats and biodiversity,
- Ecosystem interactions and energy transport between different fish species and other organisms, especially predator-prey relationships. Quantitative data on sea mammals is especially important,
- Knowledge of resilience of the ecosystem with regard to changes in climate, sea currents, and sea ice.

Technology aspects:

- Knowledge of fishing gears (trawls) that reduces the impact on bottom habitats,
- Knowledge of fishing gears that reduce emissions of greenhouse gases during fishing operations.

5.2 Pollution

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5.2.1 Current management

The national-scale management of pollution in Russia and Norway is impacted by a number of international agreements. In addition, the efficiency of management of the Barents Sea pollution strongly depends on bilateral cooperation between Russia and Norway.

5.2.2 International agreements concerning pollution

International (global and regional) agreements and conventions are of major importance in order to control and reduce the amount of pollution to the Barents Sea. These agreements include regulation of activities and restrictions of use and/or bans of hazardous substances.

For more information on applied conventions and agreements see electronic appendix on www.barentsportal.no.

One of the most important conventions 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 activity. 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 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 the measures which are necessary and 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 e.g. active regional cooperation under the 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 the adverse effects of human activities, and by contributing to the sustainable use of the seas. OSPAR's Region 1 covers the Norwegian and Russian part of the Barents Sea. So 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 longe-range transport of persistent organic pollutants and certain metals from the rest of the world is the most important pollution-related pressure on the Barents Sea, international convention and agreements concerning reduction in use and bans of hazardus subastances are of major importance. The Convention on Long-range Transboundary Air Pollution and the Stockholm Convention on persistent organic pollutants (POPs) is an important global convention regulating and/or banning the use of the most hazardous POPs.

5.2.2.1 Bilateral cooporation Norway-Russia

The Russian-Norwegian co-operation is important for the management of the Barents Sea. The co-operation have contributed and contributes to an increase in the common understanding of the pollution situation in the northern areas, strengthens the collaboration regarding control, monitoring and prevention of pollution (releases and inputs of pollutants to the environment and waste handling).

The Russian-Norwegian cooperation in the sphere of environmental protection was established in the 1990's. To ensure nuclear safety and radiation protection in the north, a joint Norwegian-Russian Expert Group was established in 1992 under the Joint Norwegian-Russian Commission on Environmental Protection (Hønneland and Rowe, 2008; Rus.-Nor. Coop., 2007). Moreover, to strengthen the co-operation between Norway and Russia in the nuclear safety field, the Norwegian government's Nuclear Action Plan was initiated in 1995 and revised in 2008. For its execution the NRPA serves as the directorate for the Ministry of Foreign Affairs. The Nuclear Action Plan must contribute 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 work with Russia (Action plan, 2009). Nuclear safety co-operation is built on several bilateral collaboration agreements (Rus.-norw.coop., 2007, www.barentsportal.no). The NRPA closely collaborates with a number of Russian governmental agencies and supervisory authorities in the area of nuclear safety, radiation protection, preparedness and environmental monitoring.

5.2.2.2 Norwegian national management

In Norway the Ministry of Environment is responsible for all regulations relating to both health and environmental effects of chemicals where no separate regulatory measures have been laid down. Medicines, cosmetics, plant protection products and chemicals for occupational use are some types of uses or products that are separately regulated.

"*The pollution control act"* is one of acts that the Norwegian Pollution Control Authority (SFT) administrates and enforces. The Pollution Control Act states that pollution is forbidden, unless it is specifically permitted by law, regulations or individual permits or licenses. It further states that it is not allowed to possess, do, or initiate anything that may entail a risk of pollution, unless this is specifically permitted by law. Almost all pollution activity in Norway is therefore based on individual permits or licences issued by SFT or the county environmental agencies. Whether a permit is granted or not, depends on the professional judgement of the pollution control authorities. The licenses contain specific requirements regarding discharges into the sea, emissions to air, handling of waste, and emergency preparedness.

SFT and the offices of the county governors target imports and sales of products and chemicals, production activities, measures to prevent the spread of pollution from polluted soil and sediments, and various types of waste management (for more information see www.sft.no).

For environmental issues regarding offshore oil and gas activities in Norwegian waters see chapter 5.3.

In Norway, the nuclear emergency preparedness organisation was established to make expertise available to handle nuclear incidents and to ensure the rapid implementation of measures to protect life, health, the environment and other important public interests. Nuclear incidents include both accidents and incidents resulting from intentional actions during peacetime and during political security crises/war. The organisation comprises the Crisis Committee for Nuclear Preparedness, in which several ministries and directorates are represented. The Norwegian Radiation Protection Authority (NRPA) is the head of and the Secretariat for the Crisis Committee, the competent national authority in the area of radiation protection and nuclear safety, the national and international point of contact and the prime mover and organizer of preparedness (NRPA, 2006d).

The NRPA administers two acts and one Royal Decree along with associated regulations:
- Act and regulations on Radiation Protection and Use of Radiation, No. 36 of May 2000.
- Act on Nuclear Energy Activities, No. 28 of May 1972.
- Royal Decree of 17 February 2006 'Nuclear Preparedness – National and Regional Organisation'.

Goals and targets
On a national level there are a number of important strategic objectives of the Norwegian policy regarding hazardous chemicals and radioactive substances that are related to pollution. For more information see electronic appendix on www.barentsportal.no.

Related to each of the strategic goals there is a set of national targets. "The 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)) sets ambitious goals for the management of the area.

The Management plan sets the following *objective* to prevent and combat pollution in the Barents Sea- Lofoten area:
- Releases and inputs of pollutants to the Barents Sea – Lofoten area will not result in injury to health or damage to the productivity of the natural environment and its capacity for self-renewal. Activities in the area will not result in higher levels of pollutants

The following *target* has been set for limiting inputs and concentrations of hazardous and radioactive substances in the Barents Sea- Lofoten area:
- By the year 2020 concentrations of hazardous and radioactive substances in the marine environment will not exceed the background levels for naturally occurring substances and will be close to zero for artificial substances (OSPAR convention). Releases and inputs of hazardous or radioactive substances from activity in the area will not cause these levels to be exceeded.

5.2.2.3 Russian national management
In Russia, the responsibility for control and protection of the environment is given to all levels of the legislative authorities - from the Duma to local municipalities; an executive power is also distributed from the federal to the regional level.

Legislative authorities develop the legal acts, directed towards the improvement of the ecological situation, based on their own initiative or input from the executive branch. Overall, all Russian active federal laws about protection of the environment comply with the respective international conventions, including the Law of the Sea, that was ratified in 1984.

Since 2008, The Ministry of natural resources and ecology has become the single responsible federal organ with executive power that develops normative acts, describes maximum-allowed levels of pollution and biota, and rules of control of pollution and damage estimates. Under the umbrella of the Ministry of natural resources, there are the several organizations to carry out the nature protection function. For more information see electronic appendix on www.barentsportal.no.

5.2.3 Issues of relevance for management of pollution

There exist several pollution management concerning issues. In this chapter three themes, long-range transboundary pollution, risk related to radioactivity and ocean acidification, have been selected to demonstrate some of the challenges.

5.2.3.1 Long range transboundary pollution

Long- range transport of pollutants, especially of POPs, radionuclides and certain metals, is currently the most important pollutant-related pressures 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 2009, see chapter 4.6). In order to maintain the Barents Sea as a clean and rich sea in the future, knowledge of transport routes, changes in transport routes due to e.g climatic changes and regulations of use of new chemicals is important.

Regulation of hazardous substances

There has over the last ten years been an increased international policy effort to reduce the use and emission of a number of POPs and many of the hazardous substances has been banned. As a result, levels of many of such legacy POPs are declining. However, the growing knowledge about POPs and how they behave in the environment have raised concerns about several groups of chemichal that have similar characteristics as legacy POPs and that are not currently regulated by international agreements. In the Arctic, there are evidence that some of these man-made chemicals, are transported to the area and that the levels are increasing in the environment (AMAP 2009). Monitoring results from the Barents Sea have also confirmed the precence of some of these groups of chemicals in the marine biota and sediments. Measured levels of these groups of chemicals are however, still much lower than levels of legacy POPs and below levels that are related to effects. On a longer term some of these substances may be a problem if not regulated . However, these groups of chemicals have not been studied as thoroughly as the legacy POPs with respect to their environmental fate and distribution in the Arctic areas (AMAP 2009). There are therefore a urgent need for increased knowledge about effects (including combined effects of pollutants), how they accumulate and levels and trends in the environment. This is important for the ongoing considerations of new chemicals for inclusion under existing national, regional and global agreements (The Stockholm Convention and the POPs protocol of UN ECE LRTAP Convention) to regulate the use and emissions of POPs.

Effects of climate change
Transport and redistribution pathways of hazardous substances to and within the Arctic and the Barents Sea is expected to be influenced by climate change processes. Reactivity, transformation, adsorption and desorption processes as well as accumulation of hazardous substances, are temperature dependent processes. It is expected that when atmospheric and ocean currents, sea and land ice changes as a result of climatic changes, also the extent and composition of potential intermediate storage media for pollutants (particle composition in air, snow and ice as well as sediment and soils) such as forests (vegetation profile and species composition etc.) in sub-Arctic areas (Russian and Norwegian sub-Arctic regions) will change. Therefore, changes in global climate and the associated environmental changes in the Arctic are expected to have significant consequences for contaminant pathways both with respect to transported chemicals, contaminant patterns and transformation processes (Macdonald et al. 2005). There are already some indications that trend with a steadily decreasing input from the atmosphere of organic pollutants during the last decade may be broken and the increased concentrations of PAH measured at Zeppelin in 2007 may be the first sign of a climate induced change in long range transport of air-borne pollutants (see also chapter 4.4.2, 4.5.1 and 4.6.4)

During the past years, numerous research activities have been initiated in order to explain the consequences of global change processes on occurrence, transport and fate of anthropogenic pollutants in remote Arctic regions. However, the "*state-of-the-science*" is still incomplete and need comprehensive assessment also in the future. Today, it becomes more and more clear that a thorough science based understanding of temporal as well as spatial distribution patterns, including comprehensive source elucidation for selected pollutants, is mandatory for a validated assessment of all factors influencing chemical transport processes (air and ocean- and ice-borne transport) as well as regional pathways leading to the accumulation of selected persistent chemicals in the Arctic ecosystem.

5.2.3.2 Risk related to radioactivity
The concentration of nuclear installations and the accumulation of radioactive waste and nuclear fuel in Northwest Russia represent a potential risk of radioactive pollution in the region, including the Barents Sea area. Significant national and international actions have been undertaken to reduce the risks of radioactive contamination in this region, but still much remains to be done.

Presently, priority areas are the removal of radioactive sources from radioisotope thermoelectric generators (RTGs), safe decommissioning and dismantling of nuclear submarines and rehabilitation of facilities used as temporary storage for radioactive material.
The removal and safe disposal of RTG and their replacements with solar panel technology in Northwest Russia is a priority area under the Norwegian action plan. RTGs have been used for powering various devices, such as lighthouses, in remote areas of the Arctic. The

remaining 11 devices, located in the Archangelsk and Nenets regions were removed in 2009 (Action plan, 2009; AMAP, 2009;NRPA,2009).

The work on safe decommissioning of nuclear submarines is in progress. As of 2008 164 of the 198 obsolete nuclear submarines of the Russian Northern fleet had been defueled and dismantled. Of the remaining 34, 9 nuclear submarines in northwest are waiting to be decommissioned (Action plan, 2009; AMAP, 2009).

A major potential risk of radioactive pollution for the local and regional environment represent facilities used as temporary storage sites for radioactive wastes, spent fuel and reactors from decommissioned submarines such as temporary storage at Andreev Bay and Gremikha (on the Kola Peninsula), and *Lepse* storage vessel (in the Kola Bay). Transport of spent fuel and radioactive wastes form these facilities to safer storage sites represents another risk (see details in chapter 4.4). The present plan suggests that transport of spent nuclear fuel and radioactive waste from Andreev Bay can start in 2013-2014. From Gremikha the removal of fuel to the Russian reprocessing plant in Mayak was scheduled to start at the end of 2008 (NRPA, 2007d; Action plan, 2009; AMAP, 2009). Further activities will also include defueling and decommissioning of the *Lepse* Floating Maintenance Base, which has been used for storing spent nuclear fuel and radioactive waste and which is in a very poor condition (AMAP, 2009). It is also expected to relocate the *Lepse* from the Atomflot site to the Nerpa Shipyard.

There are several other issues that present a potential risk of radioactive contamination in the region that could affect the Barents Sea area as well.

The safety of the ageing Kola NPP continues to be an important part of Norwegian-Russian collaboration which is anchored in a separate sub-strategy under the Norwegian Nuclear Action Plan revised in 2008 (see chapter 4.4).

Russian plans for building Floating Nuclear Power Plants (FNPP) for use in the Arctic region, and their possible export, raise new concern on nuclear safety in the region (AMAP, 2009; NRPA, 2008c). The presence of new nuclear power generation facilities in the Arctic and related technologies may affect the risk of accidents and incidents involving a release of radioactive substances to the marine environment, as well as increase the risk posed to human health and the socio-economic situation in the region (NRPA, 2007a, 2008c; AMAP, 2009). Apart from risks associated with FNPPs themselves, there is further potential for pollution arising from supporting shore based facilities designed for the purpose of refuelling, waste handling, decommissioning and other activities (NRPA, 2008c). Besides, should FNPPs be built, it will increase not only the number of reactors in the Arctic, but also the nuclear traffic to and from the Arctic where the Barents Sea area might also be involved. Such traffic would consist of vessels loaded with fresh fuel and more significantly, spent nuclear fuel and nuclear waste on the return journey.

In addition, the opening up of the Northeast Passage for increased ship traffic may also lead to the transport of nuclear materials from European reprocessing facilities through the Barents Region. Concern has also been raised about the possibility of a new transport route for spent nuclear fuel to the Russian north and along the Norwegian coastline as climate change reduces ice cover in the Arctic. In Norway, large economical and cultural interests are connected to production and export of marine food products, and past experiences have shown that only rumours of radioactive contamination in seafood can lead to economical consequences for producers.

Another potential risk is posed by the presence and operation of nuclear powered military and civilian vessels, such as nuclear icebreakers, in the region. Presently, Russia has 7 nuclear icebreakers in operation which have Murmansk as a port of registry and are in use in the Arctic region.

Recent assessments suggest that the oil and gas industry is likely to expand in the Arctic which will bring new concern on the risk of possible radioactive pollution of the marine environment. However, any potential radiological impact arising from the expansion of the oil and gas industry in the Arctic may be mitigated due to national and international policies regarding the ultimate fate of operational discharges and wastes that are likely to represent a source of TENORM to the marine environment.

5.2.3.3 Ocean acidification

Increased ocean acidification is a majaor concern since the prosess is more rapid than than similar changes experienced over the past 100 000 years. In addition, the absorption is faster in colder water. The Ocen acidification may potentially have huge effects on the ecosystem Acidification will negatively affect phytoplankton (coccolithophores), corals, molluscs, echinoderms and crustaceans. Recent research also indicates that eggs and larvae of certain fish species may be endangered. The rapid changes in the ocean carbon chemistry give vulnerable species small possibilities to adapt, and extensive changes in the marine ecosystems can be expected (e.g Orr et al. 2009, Richardson et al. 2009). More about possible effects on the ecosystem components are given in chapter 4.6.2.

There is limited scientific knowledge about effects of elevated CO_2 in the oceans. The main reason is that only very recently the topic and the seriousness of direct consequences of anthropogenic CO_2 emissions on the marine life have come to full attention of policymakers and scientists. In the Monaco declaration (2008), 155 scientists from 55 countries stated their concern about the rapid change in ocean acidification and the effect this can have on marine ecosystems and fisheries.

To face the problems ocean acidification may cause in near future in the Barents Sea, there is a critical need to increase the effort on monitoring in addition to research. There is a need for the development of highly resolved monitoring of atmospheric and surface water partial pressure of CO_2, carbonate alkalinity and pH at spatial and temporal scales over long periods of time We furthermore need to develop monitoring of the combined effects on key species and ecosystems of acidification and other simultaneous stressors.

5.3 Oil and gas activities

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The Barents Sea region is exposed to an increasing interest in oil and gas exploration and development. Currently offshore oil and gas production is limited both in Russian and in the Norwegian part of the Barents Sea. In the future this may change if oil and gas fields are developed and put into production.

5.3.1 Management

In the management of the petroleum industry, one of the main principles is to ensure regulated with a view to ensuring that the risk of both acute pollution and operational discharges is remains low. In addition, there is a focus on the responsibility of the industry themselves, and on the environmental management systems that they are obliged to have in place.

5.3.1.1 International work/agreement

The activities that goes on in the Barents Sea is strictly regulated trough national laws and regulations and trough international conventions agreements. The international agreements play a vigorous part in harmonising the regulation transverse the national regulation.

OSPAR

OSPAR (The convention for the Protection of the Marin Environment of the North-East Atlantic) is the current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. The Governments of 15 Contracting Parties and the European Commission takes part.

Decisions agreed upon by all contracting parties must be implemented in the legal framework in each country. The environmental agencies also seek to implement the recommendations.
Decisions and recommendations which restrict discharges and emissions from the offshore petroleum industry cover:

- environmental management systems ecotoxicological testing and evaluation of chemicals, and the use and reduction of the discharge of the chemicals
- the use of organic-phase drilling fluids (OPF) and the discharge of OPF-contaminated cuttings the management of produced water from offshore installations, including maximum oil content and an obligation to reduce the total amount of oil being discharged decommissioning of installations no longer in use reporting requirements. OSPAR do also work with different issues related to risk assessments, environmental monitoring, emissions to air and cutting piles on the sea bed.

Arctic council
Both Russia and Norway are member states in the arctic council together with Canada, Denmark (including Greenland and the Faroe Islands), Finland, Iceland, Sweden and the United States of America.

In 2007, *The Arctic Council Oil and Gas Assessment)*was finalized, the work being lead by AMAP (the Arctic Monitoring and Assessment Program). The document may be used as a balanced and reliable document for decision makers in support of sound future management of oil and gas activities in the Arctic.

The *Offshore Oil and Gas Guidelines* was updated in 2009. ere adopted by the Arctic Council in 2009. These guidelines are intended to be of use to the Arctic nations during planning, exploration, development, production and decommissioning of oil and gas activities.

The European Commission
In 2008, EU adopted the Marine Strategy Framework Directive. This directive constitutes the environmental component of the EUs Integrated Maritime Policy -- also called the Blue book. Both may have some impact on regulation of the offshore industry in the future.

5.3.1.2 Framework for the Norwegian petroleum activities

The requirements for the petroleum activity in the Barents Sea are considerably stricter than the standards that apply on other parts of the Norwegian continental shelf. The targets aim specifically at the reduction of discharges of hazardous compounds both in chemical products used and naturally occurring in the produced water.

General regulations
Licences to engage in petroleum activities in an area can only be obtained for areas that are open for petroleum activities. The decision to open an area for petroleum activities is made by the Parliament (Stortinget). For the areas that are open for petroleum activities, the authorities issue exploration and production licences on a case by case basis.

Before seismic surveys are carried out, notification must be sent to the Norwegian Petroleum Directorate (NPD), the Directorate of Fisheries, the Norwegian Institute of Marine Research (IMR), and the Ministry of Defence. The NPD will issue a licence to conduct seismic surveys. Environmental impact assessments (EIA) must be carried out before an area is opened for petroleum activities. The assessment is initiated and funded by the authorities. The results from the studies lead to the decision on which parts of the areas to open, and the conditions that apply in the opened areas. The Ministry of Petroleum and Energy (MPE) is the responsible authority, and the opening of the areas is done by the Parliament.

For the production phase, the operator must submit a plan for development and operations (PDO). The Ministry of Petroleum and Energy issue exploration and production licences for relatively limited areas. The licences may contain specific conditions such as a ban on exploration drilling during biologically vulnerable periods.

Before any activities could start (exploration or production drilling and before a production installation is taken into use) the operators must obtain a consent from the Norwegian Petroleum Safety Authority (PSA). In addition, the operators must obtain an environmental licence from the Norwegian Pollution Control Authority (SFT) according to the Pollution Control Act and the HSE (health, safety and environment) regulations. These licences contain specific requirements regarding discharges into the sea, emissions to air, handling of waste, and emergency preparedness.

The Ministry of Petroleum and Energy has an overall responsibility for the petroleum sector, including environmental issues. The Petroleum Safety Authority coordinates the authorities involved on a regular basis. The Norwegian Pollution Control Authority is responsible for environmental issues on a day to day basis.

The applications, EIAs, consents and licences are open to the public, except the documents regarding production licences, which will include confidential information regarding production profile, expected income to the government etc.

Before the production is shut down on a field, the operator must submit a decommissioning plan to the Ministry of Petroleum and Energy. The decommissioning activity will need licences and consents in line with what is described above for other petroleum activities.
The Government also requires operators to carry out environmental monitoring programmes on all oil fields to monitor the impact on the surrounding environment. Guidelines for environmental monitoring are issued by the Norwegian Pollution Control Authority.

Special regulations for the Barents Sea
The requirements for the petroleum activity in the Baren Sea are described in a white paper on oil and gas activities (Report to the Storting on the Oil and Gas Activities (Report no. 38 to the Storting (2001-2002)) and the most important ones are listed below:

- Injection in to the underground or another suitable technology must be used to prevent discharges of produced water.
- A maximum of 5 % of the produced water may be discharged during operational deviations provided that it is treated before discharge.
- Drill cuttings and drilling fluids must be injected into the underground or taken to shore for treatment.
- Drill cuttings and drilling fluids from the top-hole section may be discharged provided that they do not contain substances with unacceptable ecotoxicological properties, , and only if EIAs indicate that damage to vulnerable components of the environment is unlikely. Such assessments must be based on thorough surveys of vulnerable components of the environment (spawning grounds, coral reefs, other vulnerable benthic animals).
- Petroleum activities in the area must not result in damage to vulnerable flora and fauna. Areas that might be affected must be surveyed before any activities are started.
- There must be no discharges into the sea in connection with well testing.

- Oil spill response measures must be at least as effective as on other parts of the continental shelf.
- The total amounts of use and discharges/injection of produced water, drill cuttings; chemicals etc. are reported, by the different operators, in yearly reports to the Norwegian Pollution Control Authorities.

5.3.1.3 Framework for the Russian petroleum activity

The development of offshore oil and gas resources is under the competence of the Ministry of Natural Resources and Ecology (Minprirody) and its subordinate federal agency:

- Federal Agency for Exploitation of Mineral Resources (Rosnedra),
- Federal Service for Monitoring of Nature Management (Rosprirodnadzor) and
- Federal Service for the Environmental, Technological and Nuclear Monitoring (Rostehnadzor).

Main legislative acts are:

- The federal law “About continental shelf of the Russian Federation”,
- The federal law “On minerals”,
- “Agreement on share of production”.

There are also a number of directive and documents such as:

- “Maritime Doctrine of the Russian Federation for the period until 2020”,
- “Energy strategy of Russia for the period until 2020”,
- “Strategy for the research and development of oil and gas resources of continental shelf of the Russian Federation for the period until 2020” and others.

Granting the right to use areas with underground resources with the purpose of geological examination is done only in relation to those areas, which have been approved by the Ministry of Natural Resources of the Russian Federation programs of geological examination of areas with subsoil resources, restoration and rational exploitation of mineral resources – for those subsoil areas, which geological examination is funded from the state budget; The areas must also be adopted by the Ministry of Natural Resources of the Russian Federation lists of objects offered for the use, and officially published by the above Ministry according to the legislation of the Russian Federation - for those underground areas, which geological examination is financed from the own funds of users of subsoil resources.

The physical coordinates for the licensed sites are determined by Rosnedra (Federal Agency for Exploitation of Mineral Resources) and approved by Minpriroda (Ministry of Environment). Licensing agreement for exploration and extraction or extraction only defines the order of activity. Site must be registered with the Committee for the State Reserves which can be done only after complex investigations (density of profiles, exploratory drilling, etc). Extraction can be started only after the registration is completed.

License for regional geological exploration and extraction of the continental shelf, must include the following information:

- Environmental provisions for the used areas, including ecological monitoring,
- Agreed methods of compensation of damages to the living resources.
- Measures for prevention and liquidations of emergencies
- Insurance, conservation and liquidation of the structures upon completion of the work.

Seismic work on the shelf consists of two stages:

1. State research (scale 1:1 000 000 or 1:200 000), based on volumes and areas submitted by Rosnedra (Federal Agency for Exploitation of Mineral Resources), takes 2-3 years
2. Conduction of more detailed geological research based on the license issued by Rosnedra.

Environmental impact assessment is conducted and funded by the developer; results are presented for the ecological expertise conducted by Rostehnadzor (Federal Service for the Environmental, Technological and Nuclear Monitoring) in agreement with Rospotrebnadzor (trade and sanitary inspection authority), Rosprirodnadzor (Federal Agency for Exploitation of Mineral Resources) and Rosrybolovstvo (federal service dealing with fishing activities).
Environmental license for discharge is issued by Rosprirodnadzor and Rostehnadzor, but Minprirody requires “0-discharge” for the arctic shelf.

Information on license availability is open to the public and normally, licenses are given based on the open competition, but can also be assigned without the competition by a state decree (for the oil company Gasprom or Rosneft).

A decommissioning plan is a mandatory part of the project documentation and gets approved by Rostehnadzor. Monitoring guidelines should be developed by Minprirody, but as of today they do not exist and according to the current legislation – are not required for the licensing agreement; there is only a general requirement for rational and safe exploitation of mineral resources. Therefore, developers use international guidelines, in particular –Arctic Council - Arctic Offshore Oil and Gas guidelines, 2002. New guidelines were accepted in 2009 (Arctic Council: Arctic Offshore Oil and Gas guidelines; 2009).

Prior to any type of exploratory activity, project documentation is created and environmental impact assessment is planned. State environmental expertise is conducted on the federal level and its decision is adopted by Rostechnadzor with the prior agreement with Rosprirodnadzor. Rostehnadzor carries out the monitoring and supervision of safety of operations related to exploitation of mineral resources. Rosnedra is responsible via its regional (for terrestrial activity) and MORGEO (for marine activity) departments for monitoring of compliance regarding the geological issues, related to licensing agreement, keeping the state record and balance of mineral deposits and resources, and assignment and cancellation of mineral resources to the state balance in accordance with the established procedure. There have been precedents, when the license was revoked by Rosnedra due to non-compliance with the terms of the beginning of exploratory work. (see also chapter 3 for monitoring).

5.3.1.4 Cooperation between Norwegian and Russian government

Concerning environmental management issues Norway and Russia have had a Joint Commission on Environmental Protection since 1988. In 2005 a Marine Environment group was established under this commission, with the aim of enhancing the cooperation on ecosystem-based management of the Barents Sea. Under this working group a number of petroleum related projects have been carried out to increase the mutual understanding of the two countries laws and regulations related to their respective petroleum industries. The projects range from seminars comparing Norwegian and Russian environmental regulations regarding the petroleum industry, visits onboard Norwegian and Russian oilrigs, development of best practices for coastal oil spill combat and monitoring of recovery of coastal ecosystems. In 2009 a joint Norwegian - Russian safety and environment audit was carried out on an offshore object in Norway. This was an actual audit, constituting a safety team and a environment team. To increase to mutual learning the Russian team carried out the audit in accordance with Russian regulations and routines.

5.3.1.5 The preparedness in the Barents Seas

The oil companies in Norway and in Russia are required to have an oil spill preparedness plan that is intended to limit the consequences of any accident to the maximum degree possible. On the Norwegian Continental Shelf, the oil companies have established an alliance - NOFO (the Norwegian Clean Seas Association for Operating Companies) - which handles the oil spill preparedness. NOFO has divided the coastline into five regions with depots, equipment and emergency response plans for each area. The emergency response encompasses sea-going oil spill vessels, towing vessels, oil booms and oil skimmers that can pump oil up from the sea. Preparedness cooperation between local Norwegian authorities is ensured through 34 so called IUAs, which are inter-municipal bodies covering the whole country.

In Russia, large terminal and transport operators, like Lukoil and Sovcomflot, establish their own oil spill preparedness units for large projects.

It is also the duty of local authorities to maintain preparedness and take action in the event of minor instances of acute pollution within their local borders when this is not covered by private preparedness, and in instances where polluter is not able to take action or is unknown.

5.3.2 Themes to consider when developing ecosystem based management

Ecosystem based management is the management of human activities and hence on how to obtain sustainable development. This means that all activities in the area should be managed within a single context and that the total environmental pressure from activities should not threaten the structure, functioning and productivity of the ecosystems. One of the activities that could have a negative impact on the ecosystem is the petroleum industry. An important subject to consider for development of ecosystem based management is the risk of impact from accidental discharges.

Accidental discharges

Impact from the petroleum industry is discussed in chapter 2.6.3. Risk of accidental discharges is discussed in chapter 4.4.2.

Most accidental discharges of oil or chemicals are small, and caused by overfilling of tanks, leakages from pipes or transfer lines, loose fittings or couplings, valves that are open when they should be closed, and in very few cases ruptures of pipelines. Blowouts are very uncommon, but could result in large amounts of oil released. A blowout may occur if there is a loss of control during drilling. The probability of this happening is highest during exploration drilling. Based on existing knowledge, the main tasks in the future, in addition to those relating to long-range transboundary pollution, will be to deal with the risk of acute oil pollution in the Barents Sea–Lofoten area and further develop the different elements of an ecosystem-based management regime. In the context of reducing the risk for an accident it is important to seek to understand how a dangerous situation can arise and develop, with a view to implement the most relevant measures where they will be most effective in preventing risks from resulting in actual accidents and limiting the consequences if an accident does occur. The consequence of an accident will depend on the efficiency of the emergency oil spill response system.

An essential part of risk managementis to ascertain what knowledge has already been accumulated through out the activity in question. Part of the process is to identify what we know and what we do not know, what has happened in the past, what we expect in the future, and how we can reduce the risk in order to ensure that activities can be carried out safely. The precautionary principle is one of several possible risk management strategies.

While considering ecological effects of oil spills in the Barents Sea, as a part of the Arctic seas, one should be taken into account some specific traits of Arctic ecosystems structure, especially the relatively high abundance of seabirds and marine mammals in comparison with other climatic zones. These groups of marine biota are known to be the most vulnerable to oil impacts. Due to high local accumulation of seabirds in Arctic seas there may be significant mortality from the small oil spills (tens of liters) (Patin, 1999).

Knowledge gaps

Several years' experience of petroleum operations on the Russian and Norwegian continental shelves has given us a lot of knowledge about the risk of pollution from drilling and production activities and the effects of discharges. The petroleum industry is regulated with a view to ensuring that the risk both of acute pollution and the risk of effects from operational discharges remain low.

Recent use of risk analysis and modelling in the development of the Norwegian management plan for the Barents sea, and more recently for the Norwegian sea have shown severe limitations to this approach. Complex biological processes like survival of fish from larvae to adults are poorly understood biologically and therefore inherently difficult to model in a risk analysis model. Also, knowledge of toxicity of oil spills, especially in a long-term ecological perspective is still limited and a substantial gap in knowledge still exists.

More knowledge is needed about the adaptation of existing oil response equipment to Arctic conditions, particularly in order to be able to cope with oil spills in ice and response measures in the dark. The level of uncertainty as regards the causes of oil spills in the Barents Sea–Lofoten area is no higher than for other Norwegian sea areas. An acute oil pollution from shipping and petroleum activities in particularly valuable and vulnerable areas will have greater impacts in the Barents Sea area than in other sea areas, although exactly how much greater these would be is uncertain, mainly for the following reasons:

- lack of knowledge about the current situation,
- lack of knowledge about the impacts on the ecosystem.

The need for more knowledge can be grouped into different field:

- Technological development and techniques in the context to reduce the risk of accidental pollution.
- Baseline information on the ecosystem and the effect of petroleum activities (eg. larvae survival, toxicity) on the different trophic levels, including long term production outlet.
- Knowledge about the consequence on the society of acute pollution.

5.4 Maritime transport

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The Barents Sea is used by a variety of vessels type e.g. fishing vessels, tankers and bulk carriers, military vessels, other cargo vessels and passenger ships. The volume of shipping in the area will be influenced by the development in the petroleum industry in the area and the future possible cargo shipping route through the north-east passage . Transport of oil and other petroleum products from ports and terminal in north-west Russia have been increasing steadily over the past year (Chapter 4.4.4.4).

5.4.1 Management

The management of maritime transport is strictly regulated trough a combination of International legislations, conventions and standards and national comprehensive range of preventive safety measures.

5.4.1.1 International regulation

The field of shipping is extensively international. Global legislations, conventions and standards that regulate shipping are therefore desirable and play a vigorous part in harmonizing the regulation transverse the national regulation.

Examples of international organisations are: IMO (International Maritime Organisation), ILO (the UN’s international workers organisation), EMSA (the European Maritime Safety

Agency) and The Arctic Marine Shipping Assessment launched by the working group PAME.

International efforts have traditionally been organised under the International Maritime Organization (IMO) and have reflected the interest of flag states in uniform global technical standards for ships and crews, although the interests of coastal states have also been safeguarded. In recent years, the EU has been playing a more active part in this work, in response to accidents in European coastal waters, and the interests of coastal states have been given more weight. The EU has also expedited the implementation of international legislation by adopting it as community law. This has influenced the work of the IMO.

The IMO has adopted a number of global conventions to protect the marine environment from the negative impacts of maritime transport. In the present context, 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). The requirements in 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 the control of harmful antifouling systems and in 2004 a new convention regulating ballast water intake, discharge and management. Another example is the Ballast Water Convention which was approved in February 2004, and which Norway has ratified. This compels the 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 must treat their ballast water, and prior to that year all vessels must discharge their ballast water in the open sea.

As part of its work on maritime safety and antiterrorism measures, the IMO's Maritime Safety Committee has initiated the establishment of a long-range vessel identification and tracking system (LRIT). The design of the system has not yet been finalised. The system can also be used to supplement maritime safety and oil spill response measures, just as the land-based AIS network is used to identify traffic in near-shore waters.

5.4.1.2 Regulations in Norway

Norway has implemented a comprehensive range of preventive safety measures in its coastal waters by establishing and operating maritime infrastructure and services and has instituted a government oil spill response system to prevent or limit negative impacts of incidents and accidents at sea. The maritime infrastructure consists of lighthouses, buoys, signs and the physical improvement of channels to keep them clear and safe. The maritime services include the pilot service, traffic surveillance and control, electronic navigation aids, charts and notification and information services.

Traffic regulation and surveillance, reporting systems and extensive international cooperation to improve maritime safety are among the most important accident prevention measures for maritime transport. In view of the growing transit of oil tankers to and from Northwestern Russia, a mandatory routing and traffic separation scheme was established with effect from 1

January 2004 in Norway's territorial waters off the coast of Finnmark. Previously, ships carrying dangerous or polluting cargo could sail through these territorial waters close to the baseline. A minimum distance from the coast has now been set for these ships. The traffic lanes are positioned as far out towards Norway's new 12-nautical-mile territorial limit as practically possible.

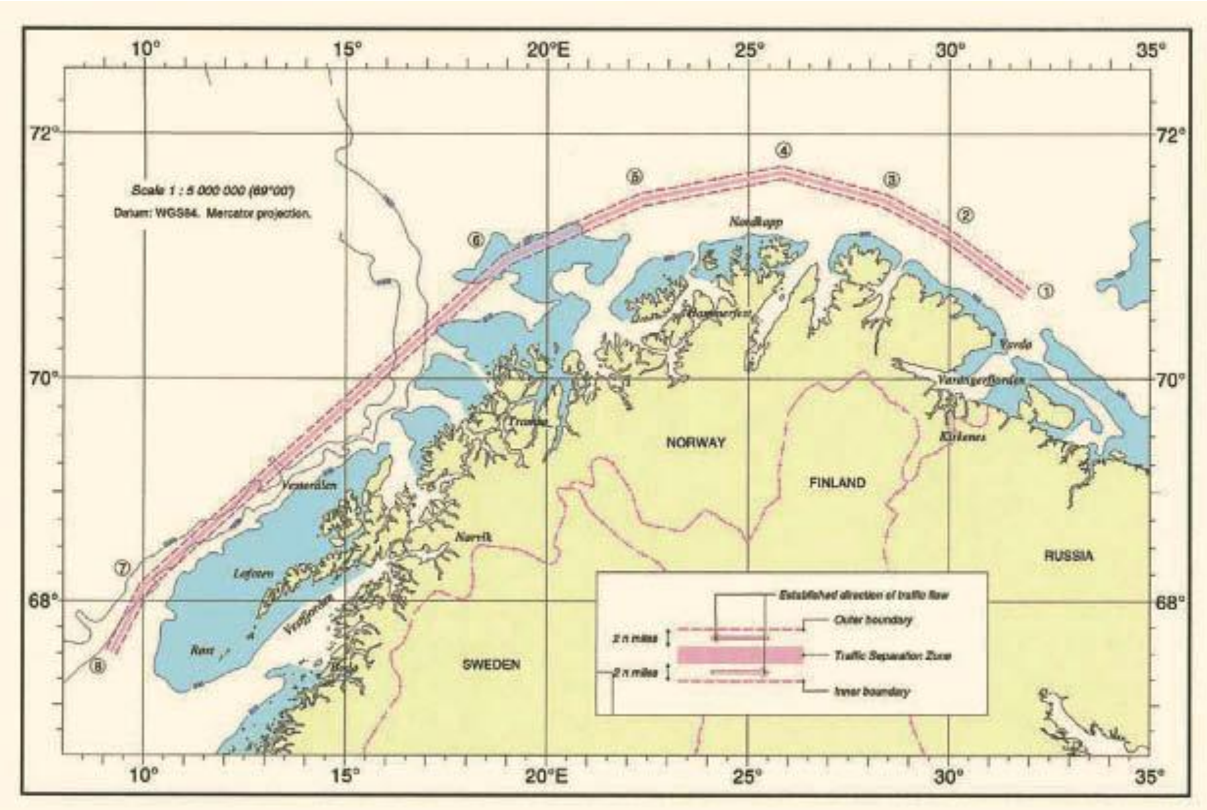

Figure 5.4.1. Mandatory routeing and traffic separation scheme outside territorial waters between Vardø and Røst (Source: Norwegian Coastal Administration).

5.4.1.3 Regulations in Russia

In Russia, the new Federal Law "On Transportation Safety" came into force in February 2007. The Russian system for safety shipping is built according to international rules and national regulations and consists of: safe shipping lanes, navigation means and information systems. The Ministry of Transport of Russia has developed the concept for building the Regional System of Safe Shipping that include: regional and local Vessel Traffic Management and Information System (VTMIS); Automatic Identification System (AIS); Global Maritime Distress and Safety System (GMDSS); Differential Global Navigation Satellite System (DGNSS) GLONASS/GPS. In the Barents Sea, the Regional System of Safe Shipping is focused on the Kola Bay. Norway and Russia are working on building coordinated regional VTMIS.

Russian Ministry of Transport has established the global automated system for monitoring and control of sea and sea-river ships location for securing sea shipping safety and following the terms of international conventions and IMO recommendations. The monitoring system is based on satellite connection system INMARSAT, and global navigation systems GLONASS and NAVSTAR. The system is coordinated by FSUE (Federal State Unitary Enterprise) Morsvyazsputnik (company dealing with marine satellite connection) of the Ministry of Transport. The Centre of Monitoring for gathering and processing information is formed by Morsvyazsputnik, State Calculation Centre and Head Centre for Communication and Satellite Systems of the Ministry of Transport. The Centre of Monitoring runs information exchange with sea ports administrations and State Salvage Department (Gosmorspassluzhba).

5.4.1.4 Emergency preparedness in Russia and in Norway

Unlike the oil industry, the shipping industry In Norway is not required to provide oil spill response equipment. The governmental emergency response system for acute pollution is therefore mainly designed to prevent and limit damage from incidents involving ships. In addition to its responsibility for the private emergency response system and operations, the Norwegian Coastal Administration therefore has operational responsibility for the governmental emergency response system for acute pollution targeted at maritime transport as well as the responsibility for ensuring that damage-reducing measures for reducing expected damage implemented by other bodies are adequate. In 2005, the Coastal Administration drew up new plans including procedures for coordination of the whole coastal emergency response system, operational emergency response services and all available expertise. The Norwegian Maritime Directorate acts as advisor to the Coastal Administration on the handling of vessels that represent an acute pollution hazard. An advisory group for acute pollution, consisting of members with environmental, fisheries and marine engineering expertise, has also been set up under the leadership of the Coastal Administration.

In Russia, the state responsibility for salvage operations and oil spill combat in the sea are taken by The State Marine Salvage Administration (Gosmorspassluzhba) under the Ministry of Transport of Russia, and their Murmansk basin Emergency-and-Salvage Department is responsible for operations in the Barents Sea. Salvage operations in case of emergencies in the sea are coordinated with specialised units of the Ministry of Emergencies of Russia and regional authorities.

According to Russian legislation, all oil-and-gas products transhipment terminals (onshore and offshore) must have oil spill contingency plans that are to be approved by the state and maintained by managed by specialized oil spill combat units – state of private.

5.4.1.5 Cooperation between Norway and Russia

The cooperation in the field of protection against oil pollution between Russian and Norway has been going on for more than 10 years. This cooperation is built on the basis of an agreement on maritime safety and environmental protection against oil pollution from 1994 defined by the Memorandum of Understanding from 2006 (Agreement between The Kingdom of Norway and The Russian Federation concerning Cooperation on the Combatment of Oil Pollution in the Barents Sea (1994)". 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 the character of practical joint activities, in which the oil pollution protection authorities from the two countries have obtained experience and have had joint exercises both in Norway an in Russia. Earlier the joint training was organised every other year; in the last few years the exercises are held at least once a year.

The Norwegian Ministry of Fisheries and Coastal Affairs with The Norwegian Pollution Control Authority (SFT), the Norwegian Coastal Administration and the Ministry of Transport of the Russian Federation represented by its oil pollution protection unit, Murmansk basin Emergency-and-Salvage Department, are the main responsible institutes in this cooperation.

Joint exercises include both Search and Rescue and fighting oil spills. From 2008, this has been split in two different exercises after a wish from the Russian side. The Search and Rescue exercise took place in 2008. In 2009, the Joint exercise was a part of the exercise Barents rescue 2009.

See also chapter 5.2.2.1.

5.4.2 Themes to consider when developing ecosystem based management

Like for the petroleum industry the maritime transport is another activity that could have a negative impact on the ecosystem when it comes to discharges of oil during an accident. An important subject to consider for development of ecosystem based management, like for the petroleum industry, is the question on how we deal with the risk for accident.

Accidental discharge

Human error is the predominant reason for accidents involving ships. Oil spills from maritime transport may be the result of groundings, collisions, structural errors or fire/explosion.

Oil and gas tankers will account for most of the increase in traffic in the Barents Seas in the near future. Exports of crude oil pose a significant risk of oil spills.

Implementation of measures such as a minimum sailing distance from the coast, traffic separation schemes and vessel traffic service centres will reduce the risk of accident and then the oil spills associated with maritime transport. As for the oil and gas industry the consequence of an accident will depend on the efficiency of the emergency oil spill response system.

Maritime transport currently involves a higher level of risk exposure in the Barents Sea than the expected risk exposure from all planned activities (Report no. 8 to the Storting). However, this conclusion is based on assumptions related to knowledge development, technological advances and the introduction of traffic separation schemes between 2006 and 2020 in line with existing plans in 2006, and may be affected by new, currently unplanned activities.

Despite the expected increase in the volume of maritime transport, the analyses indicate that the implementation of measures such as a minimum sailing distance from the coast for loaded oil tankers, traffic separation schemes and vessel traffic service centres will reduce the risk of major oil spills (>100 000 tonnes) associated with maritime transport.

Other factors that influence environmental risk are the position of the ship, the environmental value of the affected areas and the time of year when the oil spill occurs.

Introduction of alien species
Several new species in the maritime environment are a result of the discharge of ballast water. International agreements on ballast water exchange and treatment, and the general increase in awareness of the problems associated with ballast water, are expected to reduce the risk of negative impacts. It is much more difficult to reduce the risk of introduction of alien species attached to ships' hulls. This is because the most effective anti-fouling systems themselves have negative impacts on the environment.

Knowledge gaps
The need for knowledge connected to oil spill and the effect of it will be the same whether the oil came from the petroleum industry or from the maritime transport (see chapter 5.3.2).

In spite that the introduction of alien species is considered to be one of the most serious threats to the biodiversity in marine ecosystem to day we know little about the effects of alien species. Especially there are knowledge gaps concerning invasive species that may alter the structure of the whole ecosystem. When an alien species is established in a new are, history have shown us that there is little we can do to eliminate the new species.

5.5 Summary and concluding remarks about ecosystem based management

P. Arneberg (NPI), O. Korneev (SMG), O. Titov (PINRO) and J. E. Stiansen (IMR)

This subchapter is build up of three parts. The first part summaries the themes that have been highlighted as relevant for development of ecosystem based management in the previous subchapters (5.1-5.4). The second part focuses on how different themes may interact with each other. The aim of this is to illustrate how broad and holistic assessments that underlies ecosystem based management may pave the way for improvements in management. Concluding remarks are given in the third part.

Examples of knowledge gaps relevant for development of ecosystem based management have been discussed in the previous subchapters (5.1-5.4) and are not summarised here.

5.5.1 Summary of themes relevant for ecosystem based management

As mentioned in the introduction to this chapter, the themes that are discussed as relevant for the development of ecosystem based management can be of three different types:

- Instances where **impact** of human activities on the ecosystem has been demonstrated or is likely
- Instances where there is a **risk** for such impact from future activities
- Instances where there is no significant impact in the ecosystem but it has been shown or might be expected that the situation deviates from **goals** that we can expect that an ecosystem based management plan will have. Examples of such goals are listed in the introduction of this chapter.

It should be emphasized that although the summary given below covers many of the most relevant themes, it should not be considered a complete list. Rather, the highlighted themes should be looked upon as both a significant part of the basis for ecosystem-based management in the Barents Sea as well as important examples that illustrate how the contents of this report may be used to further ecosystem-based management in the area. Some issues that are clearly relevant have not been discussed, such as the concept of vulnerable and valuable areas, which is important in the management plan for the Norwegian part of the Barents Sea. The need for specific attention to risks for the loss of biodiversity and needs for protective measures for threatened species of arctic endemics within the region are examples of other relevant issues that have not been discussed in this chapter.

The themes are sorted to the categories listed above. Some of the themes may not be easily classified to one of the categories. This is commented where it is relevant.

5.5.2 Themes related to demonstrated or likely impact

The following themes can be listed under this category:

- Ocean acidification (chapter 5.2)
- Mixed fisheries, undersized fish, discard, bycatches and IUU fishing (chapter 5.1)
- Impact of bottom trawling on benthos (chapter 5.1)
- Implementing the ecosystem approach to fisheries (chapter 5.1)

Ocean acidification caused by increasing atmospheric C02 concentrations is an emerging problem, and is discussed in detail in chapter 4.6. The most important direct effects of acidification will be on organisms that calcify. This includes important groups of phytoplankton, zooplankton and benthos. Other groups, such as fish, marine mammals and seabirds may be affected indirectly through changes in their food base and other changes in the ecosystem. As discussed in chapter 4.6, the overall impact from ocean acidification may become considerable.

The second theme addresses several effects of fisheries on the ecosystem. For example, mixed fisheries may lead to overfishing of quotas because if the quota of one target species is taken, catch of this species may be discarded when fishing for other target species continues. This is in particular a problem in mixed cod and haddock fisheries. Species that need protection, in particular redfish and coastal cod, may be overfished because they are taken as bycatch in other fisheries. There are also some reports of bycatches of sea mammals and seabirds in fish nets. IUU fishing on the cod stock was a serious problem some years ago, but is now considered to be less serious.

Impact from bottom trawling on benthos has been clearly documented, but the extent of the problem has not been revealed. Thus, it is not clear whether or how biodiversity and ecosystems processes are affected. Effect on benthos from trawling is described and discussed in chapter 2.6.3.

Implementing the ecosystem approach to fisheries is listed as a theme here because changes in the ecosystem may influence the impact of fisheries management on fish stocks. For example, the capelin quota considered sustainable depends on the size of the cod stock, because cod consumes considerable amounts of capelin (see chapter 2.6.2). In a similar fashion, variation in climatic factors may affect productivity in the ecosystem (see chapter 2.6.1) and hence ultimately fish stocks.

5.5.3 Themes related to risk of impact in the future

These themes can be listed here:

- Risk of accidental discharges from oil and gas activities and ship transport (chapters 5.3 and 5.4)
- Risk of introduction of alien species from ship traffic (chapter 5.4)

No large oil spills have so far occurred from ship transport or oil and gas activities in the Barents Sea. With increasing activities, risk of accidental discharges will increase unless considerable mitigation measures are put in place. As described in chapter 2.6.3, oil spills may have serious impacts on seabirds, marine mammals and other groups, such as fish eggs and larvae.

Alien species may have considerable impact on ecosystems and is considered one of the most serious threats to marine biodiversity. Alien species may be introduced by ship traffic through discharges of ballast water or from organisms growing on ship hulls. With increasing ship traffic in the area, the risk of introductions may increase. International agreements on ballast water exchange and treatment are expected to mitigate this. However, similar measures do not exist to prevent introductions of species attached on ship hulls, and the risk of such introductions is therefore expected to increase.

5.5.4 Themes related to deviation from goals, even without impact

The following themes can be classified in this category

- Long range transboundary pollution (chapter 5.2)
- Risk of radioactive pollution (chapter 5.2)

Presently, the main source of pollutants in the Barents Sea is long range transboundary pollution. Of particular concern are POPs, because they bioaccumulate in the food chain and may be found in high concentrations in top predators. The levels of most substances have declined during the last decade due to reduced use and emission. However, the last few years, there has been an increasing trend for some of the legacy POPs. This is believed to be related to climate change. Another concern is the accumulation of new hazardous substances, not regulated by international agreements, in the Arctic.

POPs can inhibit immune-system functions and cause developmental problems in fetuses or young individuals. Such effects have been proven in top predators in the Barents Sea (polar bears, glaucous gulls). However, it is not clear whether populations are significantly affected. The theme is therefore listed here under the category “Deviations from goals without impact on the ecosystem”. If further studies should indicate that significant population effects do occur, the theme may more appropriately be listed in under the category of “Demonstrated or likely impact on the ecosystem” (5.5.1 above).

There are a number of nuclear installations and accumulations of radioactive waste and spent nuclear fuel in Northwest Russia. This represents a potential risk of radioactive pollution in the region, including the Barents Sea. Although significant national and international measures have been implemented to reduce the probability of radioactive contamination, a risk still remains in the Barents Sea. If such pollution would pass without significant effects on population dynamics of affected species, the theme is correctly classified here in the category “Deviations from goals without impact on the ecosystem”. If potential spills are indeed possible on a scale that can result in impacts on populations, the theme should be listed in the category “Risk of impact in the future” (5.5.1 above).

5.5.5 Interaction between themes and concluding remarks

It can easily be seen that themes discussed above may interact with each other. For example, if ocean acidification causes deteriorations of the food base of fish stocks, this can worsen the effect that any overfishing may have on these stocks. Similarly, if both acidification and bottom trawling affect benthic communities, their effects may add on or even amplify each other. A number of other interactions are possible. For example, if acidification, bottom trawling and overfishing should have a combined negative impact on food sources of seabirds and marine mammals in the future, accidental oil spills may get more serious impacts on already stressed populations of birds and mammals.

Thus, these examples clearly show that the types of themes listed in the previous section should not be considered in isolation when developing ecosystem based management. Rather, the important challenge is to conduct broad assessments of the combined impact of different types of human activities on the ecosystem. In such assessments, the influence of natural variation must also be considered.

The next question is of course how such assessments can be carried out. This is the subject of much work that is currently going into developing ecosystem based management in different countries. No attempt will be given here to review this work or give an answer to the question, but some comments will be given based on what is written in this report.

A sensible starting point is to look at the anthropogenic drivers that have the largest impact on the ecosystem, and analyse how they may interact. This is the approach taken in the chapter of this report where the overall influence of human impact on current status of ecosystem is discussed (chapter 4.5). The two drivers with the largest documented impact on the Barents Sea ecosystem is harvesting and climate change. After discussing the impact of each of them, the chapter ends with an analysis of how they may interact. In particular, it is pointed out that both temperature and fishing pressure are important determinants of stock development in Norwegian spring spawning herring and Northeast Arctic cod, and that these factors may interact through pathways that include other elements in the ecosystem, in particular capelin and zooplankton.

Another point is that assessments of combined effects may benefit from focusing on a limited set of questions. This is because the complexity may be overwhelming if all aspects of the development of the ecosystem are to be considered. Identifying relevant questions may therefore be an important step in the processes. The objectives of management will serve as useful guides in this work.

A question that will often be useful to analyse, regardless of management objectives, is whether the combined effect of anthropogenic drivers is so large that the ability of the system to absorb them is exceeded. If this happens, the ecosystem may shift to an alternative stable state, meaning that it may not shift back if the impact is reduced. This problem may be particularly important to consider when an ecosystem is under considerable pressure from several anthropogenic drivers.

In chapter 4.5 this question is discussed for the Barents Sea. Comparisons are made with other ecosystems in the North Atlantic where previously dominating cod stocks have collapsed and caused the systems to shift to being dominated by arthropods and pelagic schooling fish. A conclusion is that growth in stocks of pelagic fish, such as herring, combined with a reduced ability of the cod stock to control such stocks may make the Barents Sea more prone to irreversible shifts.

This conclusion should be considered preliminary, and more research is needed to identify whether it is actually a relevant description of a critical step of the dynamics of the Barents Sea ecosystem. However, spending time and resources on such analyses may greatly improve our ability to manage biodiversity and the biological resources in the Barents Sea sustainably in a situation with considerable fishing activities and growing impact from climate change, ocean acidification and increased oil and gas activities and ship transport.

5.5.6 Concluding remarks

As mentioned above, the themes that are highlighted as relevant for development of ecosystem based management in this subchapter should not be considered a complete list of issues that need to be considered. The examples should still cover a majority of the most important issues that need to be included in ecosystem-based management of the Barents Sea. It should be noted that climate change is not included on the list, although this is undoubtedly one of the most important anthropogenic drivers in the Barents Sea ecosystem. This is because climate change as a problem will typically be dealt with by other management processes.

Although many of the important issues that need to be considered are highlighted, actual management measures are discussed only tangentially. In particular, identification of particularly vulnerable and valuable areas is not discussed. This is one of the key measures in the management plan for the Norwegian part of the Barents Sea.

Rather, the scope of this chapter has been to identify problems that management needs to deal with and give some thoughts on how knowledge needs to be build to meet these problems within the framework of ecosystem-based management. An important point here is the need to consider how impact from different anthropogenic drivers may interact with each other. A particularly important question to answer is whether the combined impact of anthropogenic drivers at some point in time may grow so large that it causes considerable and irreversible changes in the ecosystem.

6 Summary and main conclusions

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Introduction

This report was initiated by the Joint Russian - Norwegian Commission on Environmental Cooperation and the work herein has been carried out in co-operation with the Joint Russian-Norwegian Fisheries Commission. The main objective is to provide a comprehensive description of the Barents Sea ecosystem using relevant scientific knowledge from both Russian and Norwegian scientist. The work has been based on the positive experiences with previous Barents Sea ecosystem status reports prepared jointly by PINRO in Russia and Institute of Marine Research in Norway. The report 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 the further development of ecosystem-based management in the Norwegian Territories within the area, via the Norwegian Barents Sea Management Plan. The Barents Sea has internationally been identified as a single large marine ecosystem (LME). The scientific basis from this project will therefore also contribute to the whole Barents Sea ecosystem being a consideration when the two countries further develop ecosystem based management in their respective parts of the sea area.

Developing an ecosystem-based management plan requires broad information about the various components and dynamics of the system as well as information about how the ecosystem may be affected anthropogenic activities. Therefore, this report gives a basic description of the major ecosystem components and their dynamics for the Barents Sea, including the physical environment. It also gives a description of human activities and discusses impact of these activities on the ecosystem. The status of major components of the ecosystem is described using the most recent data. In addition, some aspects of long-term change are discussed. Finally, examples of important issues relevant to the development of ecosystem-based management are highlighted. It should be emphasised that although core issues are highlighted, no attempt is made to give a complete list of relevant themes, but rather to point to possible directions of future work relating to ecosystem-based management for the Barents Sea.

General description of the Barents Sea ecosystem

The Barents Sea is a sub-Arctic shelf ecosystem located between 70° and 80°N. It connects with the Norwegian Sea to the west and the Arctic Ocean to the north. The dynamics of the system are strongly influenced by the inflow of warm Atlantic water from the west. This water mass is separated from Arctic Water by the ocean Polar Front, which is characterised by strong horizontal gradients in temperature, salinity and concomitant differences in biodiversity supported within the various regions. The system is also dominated by seasonally occurring sea ice, particularly in the eastern and northern parts. A distinct assemblage of species is associated with sea ice.

The Barents Sea is home to one of the largest concentrations of seabirds in the world, a diverse assemblage of marine mammals, including polar bears, and several commercially important fish stocks, the largest of which are Northeast Arctic cod, capelin and haddock. In addition, the Barents Sea is a nursery area for Norwegian spring spawning herring, one of the largest fish stocks in the world. There is also a rich community of benthic animals in the Barents Sea, numbering more than 3000 species, as well as a diverse community of zooplankton. Planktonic algae and algae attached to the sea ice both contribute to primary production in the region. Infectious organisms and free-living bacteria and virus may be important groups, but their role for the overall dynamics of the system has received little research attention. The ecosystem has been invaded by several alien species, such as the red king crab; the influence of which is being studied currently, but is still largely unknown.

Capelin is a key species in the Barents Sea ecosystem. This fish species feeds in the marginal ice zone and spawns near the coast in the southern part of the Barents Sea and thus transports large amounts of energy from the north to the south. It is important as prey for several species of seabirds, mammals and commercially important fish stocks, in particular Northeast Arctic cod and juvenile herring. Capelin is an important predator of zooplankton that can actually suppress the biomass of zooplankton in the Barents Sea. Capelin stock size has varied considerably in recent decades and has undergone three population collapses during the last 25 years. There is at present no consensus among scientists about the causes of the observed capelin recruitment failures leading to capelin stock collapses. While no one holds the view that the causes are all known, some suggest that the collapses are mainly a consequence of predation on capelin larvae from increased amounts of juvenile herring, others suggest several factors as likely to cause capelin collapses, including climatic fluctuations, predation from fish and marine mammals and fisheries. What-ever the cause, these collapses have had far reaching consequences for other species in the ecosystem, including a severe food shortage for the Northeast Arctic cod stock, collapses of seabird populations and food shortage and massive migrations in seal populations. It should, however, be noted that the ecosystem consequences of the first collapse (late 1980s) was much more severe than during the two later collapses, probably because more alternative prey were available for the predators during the latter collapses.

Variations in water temperature have important effects on the Barents Sea ecosystem. In particular, periods of high temperature tend to stimulate recruitment of Northeast Arctic cod and Norwegian spring spawning herring and other fish stocks. Indirectly, recruitment of capelin may be impaired by high temperatures because of increased predation from larger amounts of juvenile herring drifting into the area from spawning grounds along the Norwegian coast. Higher water temperatures, or changes in the characteristics of the Polar Front, are often accompanied by a decrease in sea ice cover and thereby a negative impact on ice-dependent species. Predicting the response of primary productivity to temperature variation is associated with uncertainty because the amount of light reaching the water column and supply of nutrients necessary for primary production may respond in opposite directions. When it gets warmer, amount of light will increase because more sea ice is melted away. At the same time, nutrient supplies may decrease because warming and increased input of freshwater from sea ice melting can lead to increased stratification of the water column, thus reducing the mixing of nutrient rich deepwater with the layers higher in the water column where primary production occurs.

The anthropogenic driver with the largest documented effects on the Barents Sea ecosystem is currently fisheries. Negative impacts of fisheries include overfishing of several of the smaller stocks and damage to benthic communities caused by bottom trawling. In addition, climatic changes have considerable effects on the system. The climate changes likely represents both natural variations and effects of anthropogenic emissions of CO_2 and other greenhouse gases. The relative importance of these two sources is not completely understood. Reproductive failure and negative population trends in ice-dependent marine mammals are possible effects of climate change. The Barents Sea is presently a relatively clean ocean with respect to pollution, however, it receives long-range transboundary transported pollution through advection, in particular PCBs and other persistent organic pollutants as well as some inorganic contaminants (e.g., Hg and Pb). These substances are detectable in biota, but to date significant effects are limited to top predators, such as polar bears and glaucous gulls. Other transboundary contaminants found in the Barents Sea area are radioactive substances. Their present concentrations are too low to have any impact on marine organisms, but risk of significant contamination exists from local sources. Oil and gas activities and ship transport have thus far had no significant direct impact on the ecosystem, but this may change with the expected increase in the level of activity in the future. Ocean acidification caused by anthropogenic emission of CO_2 is an emerging problem that might have a large impact on the Barents Sea ecosystem in the future.

Current status of the ecosystem

Important aspects of the status of ecosystem components and human activities as revealed by the most recent data are:

- Temperatures were generally higher than average throughout 2008, but lower than the two previous years. Average sea-ice extent has declined during the last three decades and was below average in 2008 but higher than in 2007.
- The stocks of capelin, Northeast Arctic cod and haddock are all increasing. Stocks of shrimp and saithe have decreased the recent years. According to ICES, all five stocks are harvested in a sustainable manner and have full reproductive capacity. The stock of polar cod is at a high level. The stocks of Greenland halibut, golden redfish, deep-sea redfish and coastal cod are at low levels. There are indications that the Greenland halibut stock is increasing and there are signs of improved recruitment in deep-sea redfish. The amount of juvenile herring and blue whiting, which are not fished in the Barents Sea, has decreased during recent years and is at present at a low level. Several species of fish in the Barents Sea are listed on the Norwegian Red Lists of threatened species.
- Zooplankton biomass has dropped since 2006 and was below the long-term mean in 2008. It was higher in the eastern parts of the Barents Sea, possibly as a result from low predation pressure from capelin and polar cod, which were mainly distributed in other areas in 2008.

- Biomass of benthic organisms has varied substantially through time and between areas in recent years. Some of this variation is due to changes in populations of snow crab and red king crab. Long-term changes in the benthic community through the 20th century have been linked to temperature variability and intensity of bottom trawling, but the role these factors play in the observed variation in recent years cannot be identified with certainty.
- Population data are scarce for most species of marine mammals in the Barents Sea, making it difficult to identify population trends and their possible underlying causes. For harp seals and hooded seals, existing data have shown that population size and/or pup production are probably being negatively affected by declining sea ice. Ringed seal reproduction has been negatively impacted by recent poor ice years in Svalbard (2006, 2007 and 2008), and the poor production is bound to cause declines in the adult population when these age cohorts should have come into the breeding population. Stocks of harbour seals and grey seals in Norwegian sector of the Barents Sea are subject to fishery-related mortality and hunting mortality that in combination are unsustainable. Harbour porpoises are also subject to by-catch in fisheries, and in order to sustain current levels of by-catch, immigration from outside the Barents Sea is required. Several species of marine mammals in the Barents Sea are listed on the Russian or Norwegian Red Lists of threatened species.
- The situation for seabirds in 2008 was characterised by continued declining population trends and breeding failure of several species in the western parts of the Barents Sea, in particular northern fulmar, black-legged kittiwake, razorbill, Atlantic puffin and common guillemot are experiencing declines. This is similar to trends seen over much of the Northeast Atlantic in 2008, but in contrast to the situation in the eastern and northern parts of the Barents Sea, where seabird populations appears to be generally stable or increasing. The situation in the eastern Barents Sea including the Pechora Sea is however difficult to assess due to lack of monitoring data. The factors responsible for the declining trends in the western parts of the region probably involve food shortage, predation from an increasing population of white-tailed eagles and lagged effects from previous by-catch in fisheries. There are several Red Listed species of seabirds in the Barents Sea.
- As described above, the major commercial fish stocks in the Barents Sea are harvested sustainably, whereas some of the smaller stocks are overfished. The quota for minke whales is considered precautionary, conservative and protective and quotas and catch rates for harp seals are considered sustainable. The harvest rate of red king crab is high and it remains to be seen how this will affect the population The general level of discarding from fisheries in the Barents Sea is not known. The general rate of by-catches of fish has declined during recent decades, but this issue is still a problem.
- The Barents Sea is relatively clean from pollution. The exception is PCB and other persistent organic pollutants (POPs) that are still occurring in significant concentrations in top predators like polar bears and some seabirds. Due to regulations and bans of several POPs (e.g PCB and HCB) there has been a decreasing trend in input to the Barents Sea the last decade. However, in the last few years, increasing trends are again seen for some of these substances. Levels of radioactive substances have been decreasing in recent years, but there is still a risk of significant radioactive pollution from several local sources, such

as radioactive waste containers dumped in the Barents and Kara Seas by the former Soviet Union (FSU) and sunken submarines in the Norwegian Sea and the Barents Sea.

- No major accidental spills of oil from ship transport or oil and gas activities have occurred in the Barents Sea in 2008 or the recent past.

Aspects of future change

The following aspects of possible long-term changes in the ecosystem are discussed in the report:

- Although models generally project that the climate in the Barents Sea will get warmer, considerable differences exist between climate models. Predicting the magnitude and nature of the warming that is likely to occur is therefore associated with considerable uncertainty. It is highly likely, however, that any significant warming will cause shifts in species ranges. This means that more temperate species will become established in the area and that species already present, such as capelin and Northeast Arctic cod will tend to shift toward the north and east within the Barents Sea. In addition, sea ice extent will be reduced, and this will have a negative impact on ice-dependent flora and fauna, such as polar bears. Reduction in sea ice extent may also lead to increased primary productivity, if nutrient supply is not reduced significantly due to increased stratification in the water column. An increase in primary productivity coupled with other positive effects of increased temperature on fish growth and reproduction, may cause productivity of cod, haddock and other commercially important species to increase. However, negative effects on prey species may also occur. Thus, overall effects on fish productivity are hard to predict. Similarly, the many complex ways in which species interact creates considerable uncertainty in any set of predictions as to what the overall response of climate warming to the ecosystem will be.
- Anthropogenic emissions of CO_2 are causing acidification of the world oceans because CO_2 reacts with seawater to form carbonic acid. Currently, acidity has increased by about 30% (reduction in pH by about 0,1 units). In 2100, pH reductions in the order of 0.2-0.3 units are predicted. This will significantly reduce the ability of organisms to build calcium carbonate shells and skeletons and it might also have other effects on organisms. The direct effects are expected to be most pronounced for phytoplankton, zooplankton and benthos. Fish, seabirds and marine mammals can be affected indirectly, possibly making ocean acidification one of the most important anthropogenic drivers in the Barents Sea in the future.
- Age at maturity of Northeast Arctic cod has decreased in recent decades. If this trend continues, it could impair cod recruitment and change the role of cod as a top predator in the system.
- Climate change may alter the transport patterns for long range transboundary pollution.

Issues relevant for ecosystem management

The following themes are highlighted as examples of issues that are relevant for development of ecosystem-based management:

- Ocean acidification

- Mixed fisheries, undersized fish, discard of catches, bycatches and IUU fishing
- Impact of bottom trawling on benthos
- Risk of accidental discharges from oil and gas activities and ship transport
- Risk of introduction of alien species from ship traffic
- Long range transboundary pollution that is transported by air and water currents.
- Risk of radioactive pollution

It should be emphasised that although this covers many of the most relevant themes, it should not be considered a complete list. Therefore, the highlighted themes should be looked upon as both a significant part of the basis for ecosystem based management in the Barents Sea as well as important examples that illustrate how the contents of this report may be used to further develop ecosystem-based management in the area. Some issues that are clearly relevant have not been discussed, such as the concept of vulnerable and valuable areas, which is important in the management plan for the Norwegian part of the Barents Sea. The need for specific attention to risks for the loss of biodiversity and needs for protective measures for threatened species of arctic endemics within the region are examples of other relevant issues that have not been discussed in the report.

The different themes described above may interact with each other. For example, if ocean acidification causes deteriorations of the food base of fish stocks, this can worsen the effect that any overfishing might have on these stocks. Similarly, if both acidification and bottom trawling affect benthic communities, their effects may be additive or even amplify each other. When developing holistic ecosystem-based management, an important challenge is therefore to conduct broad assessments of the combined impact of different types of human activities on the ecosystem.

For an ecosystem that is under considerable pressure from several anthropogenic drivers, it is particularly important to analyse whether their combined effects are so large that the ability of the system to absorb them may be exceeded, causing the ecosystem to shift into another stable state. Such changes have happened in several marine ecosystems, where collapses of cod stocks caused by overfishing, possibly exacerbated by climate variation, have triggered fundamental changes in the ecosystems that may not be possible to reverse. In the Barents Sea, impacts from climate change and ocean acidification are expected to increase in the future, while the level of fishing activities will remain high and increased oil and gas activities and ship transport are expected. To secure sustainable management of the area, it can therefore be helpful to perform the type of analyses described above that assess whether the combined impacts of all of these various anthropogenic drivers are likely to put the stability of the ecosystem at risk.

Future needs for monitoring and integrated status reports

The expected increases in the number and type of impacts on the ecosystem put a premium on more extensive monitoring in the future. New monitoring methodology and technology should be developed and implemented to fill the spatial and temporal gaps in current knowledge and on-going monitoring efforts. However, many ecosystem components will still depend on traditional surveys for necessary data collection for many years. During such surveys there is a strong need to capture information simultaneously from as many ecosystem components as possible to enable integrated and cost effective sampling. Developing a joint Russian-Norwegian monitoring program for the Barents Sea would be a useful measure for achieving this. Also, much of the knowledge we have today is due to the foresight of scientists that started regular long-term monitoring programs several decades ago, at a time when their usefulness in addressing current challenges from climatic change, ocean acidification and other emerging issues were unknown. Maintenance of our long-term time series should clearly remain a priority, and new technology and new programmes should be introduced to complement and expand current activities.

In addition, there is a strong need for aggregating the knowledge from observations and scientific progress in different fields. Therefore regular status reports, like this one, are essential to expose important issues and changes in the ecosystem to decision makers, as well as providing a tool for information-sharing among scientist in different fields. This sort of status report should be incorporated, as a standard product, into the pathway towards a bi-national ecosystem-based management system.

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