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JOINT PINRO/IMR REPORT ON THE STATE OFTHE BARENTS SEA ECOSYSTEM IN 2006 WITH EXPECTED SITUATION AND CONSIDERATIONS FOR MANAGEMENT

Institute of Marine Research - IMR

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Joint PINRO/IMR report on the state of the Barents Sea ecosystem in 2006, with expected situation and considerations for management

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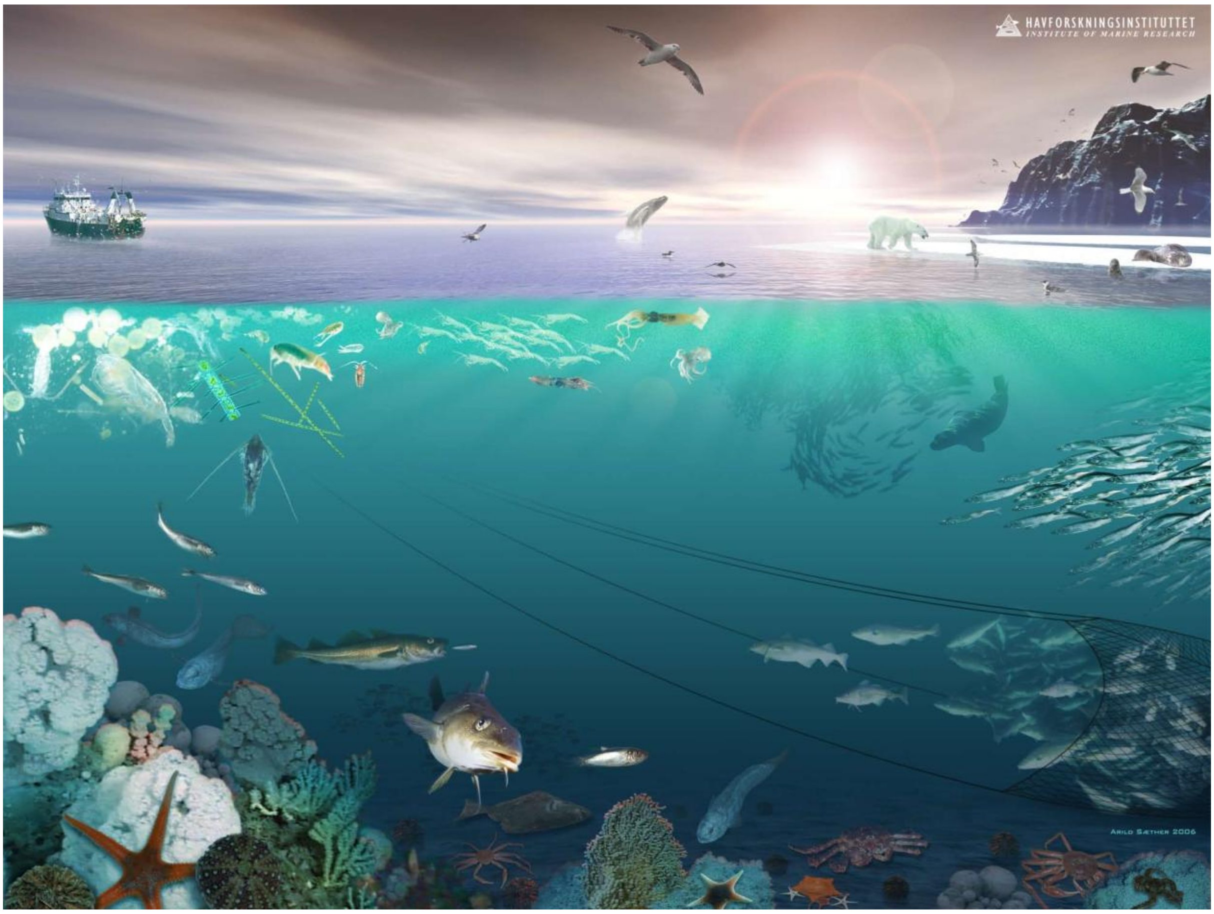

Figure 1.1. Illustration of the rich marine life and interactions in the Barents Sea.

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Contents

1 Introduction

By J.E. Stiansen and A. A. Filin

The Barents Sea is an area of intensive human activity. Historically human activity has related to fishing and hunting of marine mammals. Nowadays human activities also involve transportantion of goods, oil and gas related activity and tourism. The large-scale harvesting in the Barents Sea has strong impact not only on the state of commercial species but also on the ecosystem as a whole. On the other hand, the ecosystem is strongly influenced by climatic conditions. Year-to-year variations in the strength of inflow of Atlantic water lead to adjustments in the ecosystem and, hence, to changes in fish production. In addition to climatic conditions, which govern the formation of primary biological production and feeding conditions for fish as well as the survival of their progeny, an important factor that influences the abundance and dynamics of commercial species is inter-specific trophic relations.

The need for an ecosystem approach to the management of marine biological resources is generally recognized nowadays as the future path of management. The ecosystem approach is variously defined, but principally puts emphasis on a management regime that maintains the health of the ecosystem alongside appropriate use of the marine environment, for the benefit of current and future generations (Jennings, 2004). The basis for ecosystem approach should be the scientific knowledge about ecosystem structure and function. To achieve this it is necessary to conduct monitoring of the state of ecosystem and identify main indicators that show the health of ecosystem by taking into account both natural variations and impact from human activity. Such kind of information needs to be available at frequently updated periods if it is to be used for evaluation of the current ecosystem situation, making projections and putting the knowledge into operational use.

The work of identifying important ecosystem information for the fish stocks, and further trying to implement this knowledge into the fish stock assessment and predictions, has developed much in the last few years. However, already in 1975 the relationship between cod, haddock and capelin was mentioned in the AFWG assessment report (ICES, 1975). Hopefully, the gathering of information on the ecosystem in this report will lead to a better understanding of the complex dynamics and interactions that takes place in the ecosystem, and also contribute to reaching an ecosystem based management of the Barents Sea.

At the annual March meeting in 2006 between scientists of IMR and PINRO it was decided to begin the preparation of an annual joint status report on the Barents Sea ecosystem. It was considered that the information from this report at first would find application at the Arctic Fisheries Working Group (AFWG) as basis for the inclusion of ecosystem consideration in the advice on fishery management. However, the scope of this report is much wider. Thou the main target group of this report are the scientific community it should also prove useful for other groups, such as e.g. managers, non-governmental organisations and individuals that are interested in the scientific basis for our understanding of the ecosystem and its interactions.

The current issue is the second annual report, and can also be found electronically at (e.g. http://www.imr.no/english/imr_publications/imr_pinro), and was distributed to scientists, managers, environmental and fishery organisations and polititions.

The report is divided into 7 main chapters. In chapter 2 the typical situation is given, and also the most important links in the ecosystem are identified. Chapter 3 is describing the impact from the fisheries on the ecosystem. Chapter 4 gives an overview of the large effort that is put into surveillance. Chapter 5 shows the present situation, often in a historical perspective. Emphasis is given to situations that deviate from the normal conditions. Also effort has been put on giving expectations for the near future, when possible. Chapter 6 describes how ecosystem information, and models that use this information, can be implemented into fishery management as a step towards an ecosystem approach to fishery management. Polution is described in 7, and in chapter 8 hazzards and risks for sudden events are identifiyed and discussed.

2 General description of the ecosystem

2.1 Overview of the ecosystem

By Å. Høines, A. Filin, V.K. Ozhigin and J.E. Stiansen

The Barents Sea is a high latitude ecosystem located between 70 and 80ºN. It is a shelf area of approx. 1.4 million km^2, which borders to the Norwegian Sea in the west and the Arctic Ocean in the north. The average depth is 230 m, with a maximum depth of about 500 m at the western entrance. There are several bank areas, with depths around 50-200 m. The general circulation pattern (Figure 2.1) is strongly influenced by the topography and is characterised by an inflow of relatively warm Atlantic water and coastal water from the west. This current divides into one southern branch, which flows parallel to the coast eastwards towards Novaya Zemlya, and one northern branch, which flows into the Hopen Trench. The Coastal Water is fresher (has lower salinity) than the Atlantic water, and has a stronger seasonal temperature signal. In the northern part of the Barents Sea fresh and cold Arctic water flows from northeast to southwest. The 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 interannual variability in ocean climate related to variable strength of the Atlantic water inflow and exchange of cold Arctic water. Thus, seasonal variations in the hydrographic conditions are quite large.

The Barents Sea is a spring bloom system, and during winter the primary production is close to zero. The phytoplankton bloom has variable timing throughout the Barents Sea, and it also has high interannual variability. The spring bloom starts in the south-western areas and penetrates towards north and east along with the retraction of ice as it melts. In early spring the water is mixed, from surface to bottom, and even though there are nutrients and light enough for production, the main bloom does not appear until the water becomes stratified. Fish and mammals have similarly directed 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 stratification of the water masses in the different parts of the Barents Sea may occur in different ways; through fresh surface water due to ice melting along the marginal ice zone, through solar heating of the surface waters in the Atlantic water masses, and through lateral spreading of coastal water in the southern coastal region (Rey 1981). The dominating algal group in the Barents Sea is diatoms like in many other areas (Rey 1993). Particularly, diatoms dominate the first spring bloom, and the most abundant species is *Chaetoceros socialis*. The concentrations of diatoms can reach up to several million cells per litre. The diatoms require silicate and when this is consumed other algal groups such as flagellates take over. The most important flagellate species in the Barents Sea is *Phaeocystis pouchetii*. However, in individual years other species may dominate the spring bloom.

Zooplankton biomass has shown large variation among years in the Barents Sea. Crustaceans form the most important group of zooplankton, among which the copepods of the genus *Calanus* play a key role in this ecosystem. *Calanus finmarchicus*, which is most abundant in the Atlantic waters, is the main contributor to the zooplankton biomass. In the Arctic waters of the Barents Sea *C. glacialis* dominates the zooplankton biomass. The *Calanus* species are predominantly herbivorous, feeding especially on diatoms (Mauchline, 1998). Krill (euphausiids), also a group of crustaceans, plays a significant role in the Barents Sea ecosystem as food for fish, seabirds and marine mammals. The Barents Sea community of euphausiids is represented by four abundant species: neritic shelf boreal *Meganyctiphanes norvegica*, oceanic arcto-boreal *Thysanoessa longicaudata*, neritic shelf arcto-boreal *T. inermis* and neritic coastal arcto-boreal *T. raschii* (Drobysheva, 1994). The two latter species make up 80-98% of the total euphausiid abundance. The species composistion in the Barents Sea euphausiid community are characterized by year-to-year variability, most probably due to climatic changes (Drobysheva, 1994). The observations showed that after cooling the abundance of *T. raschii* increases and the abundance of *T. inermis* – decreases, while after a number of warm years the abundance of *T. inermis* grows and the number of the cold-water species becomes smaller (Drobysheva, 1967). The advection of species brought from the Norwegian Sea is determined by the intensity of the Atlantic water inflow (Drobysheva, 1967; Drobysheva *et al.*, 2003). The krill species are probably all omnivorous, feeding on phytoplankton by filter-feeding during the spring bloom, and on small zooplankton at other times (Melle *et al.*, 2004).

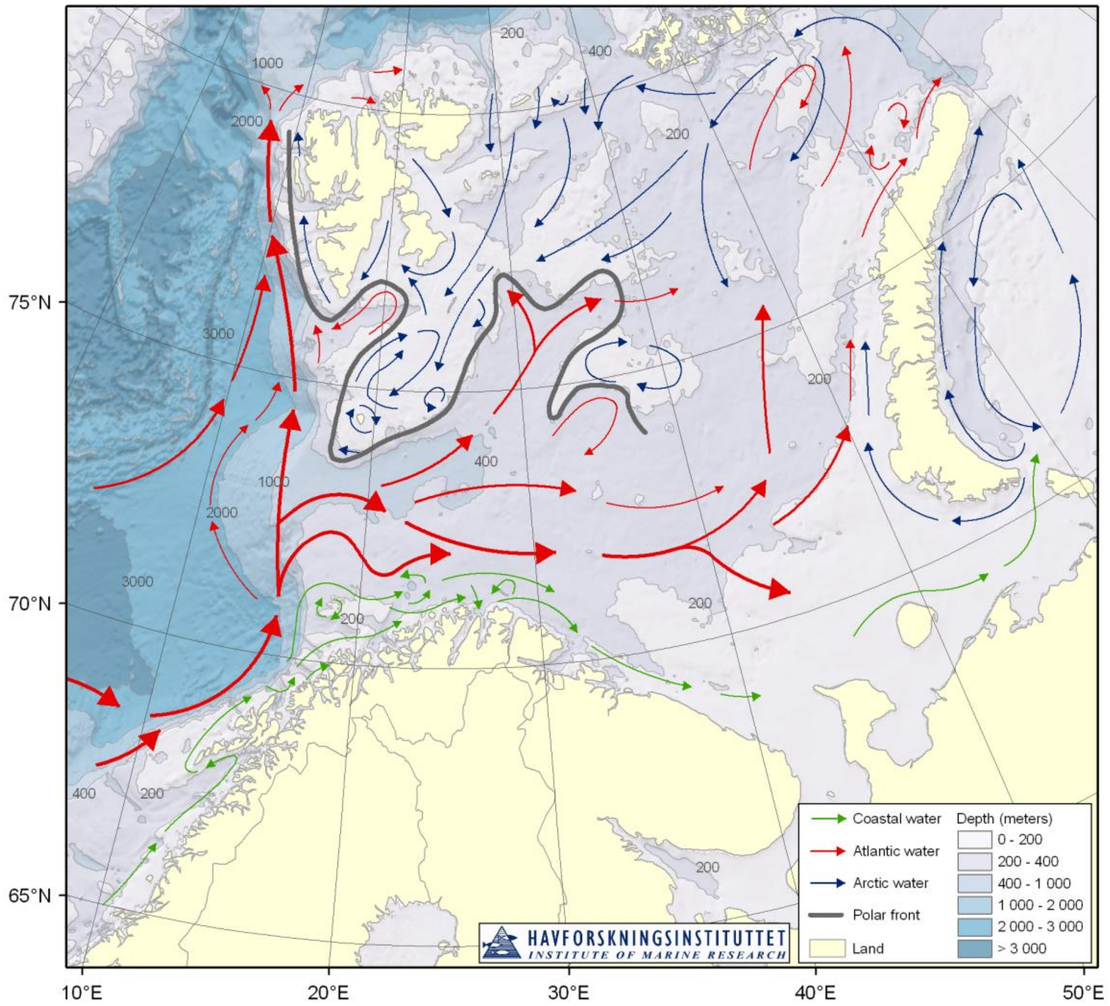


Figure 2.1. The main features of the circulation and bathymetry of the Barents Sea.

Three abundant amphipod species are found in the Barents Sea; *Themisto abyssorum* and *T. libellula* are common in the western and central Barents Sea, while *T. compressa* is less common in the central and northern parts. *T. abyssorum* is predominant in the sub-arctic waters. In contrast, the largest of the *Themisto* species, *T. libellula*, is mainly restricted to the mixed Atlantic and Arctic water masses. A very high abundance of *T. libellula* is recorded close to the Polar Front. Amphipods feed on smaller zooplankton with copepods forming an important part of their diet (Melle *et al.*, 2004).

The bottom fauna of the Barents Sea make up more than 3,050 invertebrate species (Sirenko 2001). Most of the area is covered by fine-grained sediment with coarser sediment prevailing on the relatively shallow shelf banks (<100m) or in the sub littoral zone around islands (Zenkevitch, 1963). Stones and boulders are only locally abundant. The most south-westerly parts of the Barents Sea are influenced by Atlantic fauna with the diverse warm-water fauna decreasing and cold-water species increasing to the east and north. Benthic communities are dependent on inputs of organic matter, consequently characteristics of the overlying pelagic ecosystem are largely responsible for variation in the species composition in the benthos. Three species of bottom invertebrates – Northern shrimp (*Pandalus borealis*), Iceland scallop (*Chlamys islandica*) and red king crab (*Paralithodes camchaticus*) are of economic importance. The red king crab was introduced into the Barents Sea in the 1960s. Presently it's the largest predating crustacean in the area. Shrimp is one of the most important food objects of cod, and plays an important role in the Barents Sea ecosystem.

The Barents Sea is a relatively simple ecosystem with few fish species of potentially high abundance. The most important of these are Northeast Arctic cod, Northeast Arctic haddock, Barents Sea capelin, polar cod and immature Norwegian Spring-Spawning herring. The last few years there has in addition been an increase of blue whiting migrating into the Barents Sea. The distribution of species in the Barents Sea depends considerably on the position of the polar front. Variation in the recruitment of some species, including cod and herring, has been associated with changes in the influx of Atlantic waters into the Barents Sea.

Cod, capelin and herring are key species in this 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 large range of prey, including the larger zooplankton species, most of the available fish species and shrimp. Capelin feeds on the zooplankton production near the ice edge and farther south, and in most years it is the most important prey species in the Barents Sea, serving as a major transporter of biomass from the northern Barents Sea to the south (von Quillfeldt and Dommasnes, 2005). Herring, as a prey for cod, is the only other prey item with similar abundance and energy content as capelin. At the same time herring is also a major predator on zooplankton.

Marine mammals, as top predators, are significant ecosystem components. About 24 species of marine mammals regularly occur in the Barents Sea, comprising 7 pinnipeds (seals), 12 large cetaceans (large whales) and 5 small cetaceans (porpoises and dolphins). Some of these species have temperate mating and calving areas and feeding areas in the Barents Sea (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 rare, either because this is natural (like beluga whale *Delphinapterus leucas*) or because of historic exploitation (like bowhead whale *Balaena mysticetus* and blue whale *Balaenoptera musculus*).

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

The Barents Sea holds one of the largest concentrations of seabirds in the world (Norderhaug *et al.,* 1977; Anker-Nilssen *et al.* 2000). About 20 million seabirds harvest approximately 1.2 million tonnes of biomass annually from the area (Barrett *et al.,* 2002). About 40 species are thought to breed regularly around the northern part of the Norwegian Sea and the Barents Sea. The most typical species belong to the auk and gull families.

2.2 Geographical description

By D. Howell and J.E. Stiansen

The Barents Sea is a shelf area, which borders to the Norwegian Sea in the west and the Arctic Ocean in the north and is part of the continental shelf area surrounding the Arctic Ocean. The extent of the Barents Sea is limited by the continental slope between Norway and Spitsbergen in the west, the top of the continental slope towards the Arctic Ocean in north, Novaya Zemlya in east and the coast of Norway and Russia in the south (see Figure 2.1).

The Barents Sea covers an area of approx. 1.4 million km^2. The average depth is 230 m, with a maximum depth of about 500 m at the western entrance. There are several bank areas, with depths around 100-200 m. The three largest are the Central bank, the Great bank and the Spitsbergen bank. Several troughs over 300m deep run from the central Barents Sea to the northern (e.g. Franz Victoria Trough) and western (e.g. Bear Island Trough) continental shelf break.

The Barents Sea has been involved in two major orogenic (mountain building) episodes. The first was during the Caledonian orogeny (around 400 million years ago), the second around 240 million years ago during the Uralian orogeny. Subsequent erosion and collapse of the orogenic belts produced an extensive shallow marine basin system, and the Barents Sea area has been either an intra- or epi- continental sea since the late Paleozoic. 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 dating from the late Paleozoic onwards. Carbonates (limestone) dominate the late Paleozoic, 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 has been 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. The ice cover in the Barents Sea was part of a larger ice sheet that covered north Russia, Scandinavia, parts of northern Europe and probably extending into the North Sea and northern and central Britain. In the Barents Sea the ice sheet was anchored to the islands and shallow banks, with fast flowing ice-streams existing in the major trough systems of the Barents Sea, a situation comparable to the West Antarctic Ice Sheet today (Howell *et al.*, 1999). The 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 the Bear Island Trough (Howell and Siegert, 2000).

The marine life in the Barents Sea, as we know it today, therefore only 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. The thickness of this sediment layer varies over the whole sea, due to underwater topography, currents and resuspenison. A major bottom mapping project, the MAREANO project (http://www.mareano.no) is currently in progress, which aims to give highly detailed information on the structure and topography of the Barents Sea.

2.3 Climate

By R. Ingvaldsen, P. Budgell, A. L. Karsakov, V. K. Ozhigin, A. P. Pedchenko,O. Titov and B. Ådlandsvik

2.3.1 Atmospheric 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 environment 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, 1993, 2000).

The North Atlantic Oscillation (NAO) (e.g. Hurrell *et al.*, 2003) is a predominant, recurrent athmospheric pattern of seasonal and long-term variability in the North Atlantic (illustrated in Figure 2.2). Climatic conditions of the Barents Sea are determined by both Atlantic and Arctic climatic systems. Winter NAO index explains only about 15-20% (R^2=0.14-0.22) of interannual variability in air and sea temperature in the southern Barents Sea (Ozhigin *et al.*, 2003).

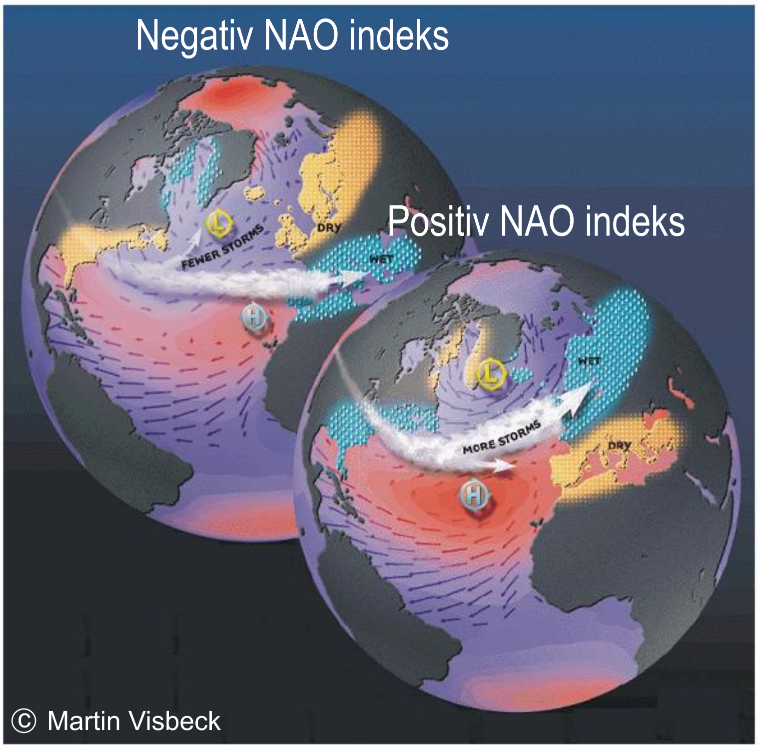


Figure 2.2. A positive NAO phase (bottom right globe) is characterized by a marked difference in air pressure between the low-pressure centre near Island and the high-pressure centre further south in the North Atlantic. In a positive NAO phase the dominating winds will be stronger than average and have 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 weaker, with opposite responses (graphics from Martin Visbeck, Lamont-Doherty Earth Observatory, USA).

The NAO influences on the atmospheric variability in the Barents Sea in winter through, among other things, the Icelandic low (Ingvaldsen *et al*., 2003). In cold season, a low-pressure trough stretches from Iceland to the central Barents Sea, and lows frequently travel along it bringing warm air of the Atlantic towards Novaya Zemlya (Figure 2.3). The southern Barents Sea is usually dominated by southwesterly winds, which contribute to increase in advection of warm Atlantic water to the area. In the northern part of the sea, cold northeasterlies predominate.

In summer, contrasts in sea level pressure are well pronounced only over the northeast Atlantic (Figure 2.4). In the Norwegian and Barents Seas horizontal gradients of pressure are rather small and, 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 in May-August.

The long-term seasonal mean sea level pressure patterns greatly influence spatial variation of air temperature in the Barents Sea. Figure 2.5 shows climatic seasonal cycle of air temperature at some stations around the Barents Sea: Spitsbergen 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 GMO Im. E.T. (80.6°N, 58.0°E). As one can see in Figure 2.5, the long-term mean air temperature over the Barents Sea ranges from about -7 °C in the south to -25 °C in the north in January and from 12 °C to 1 °C in the corresponding parts of the sea in July.

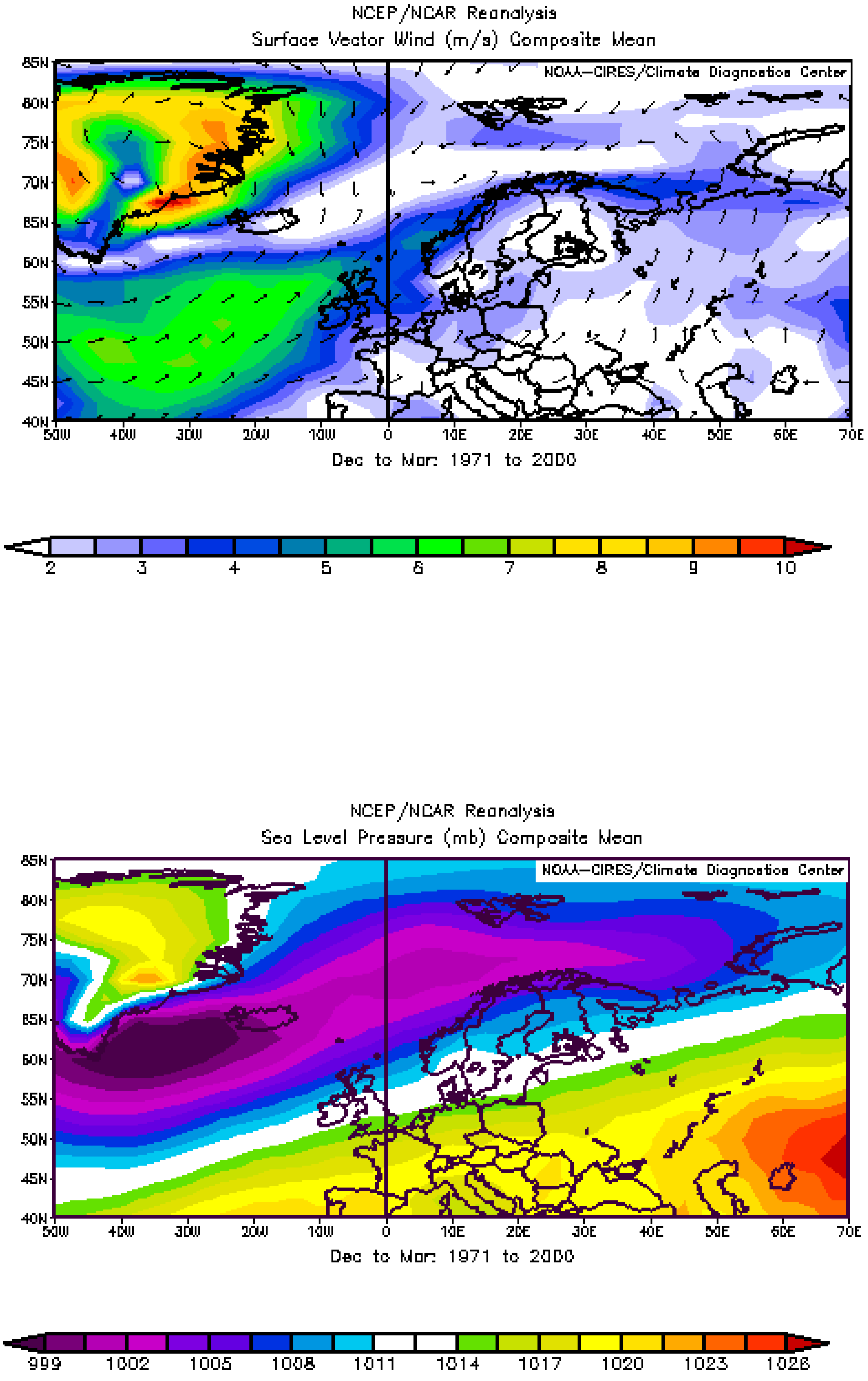
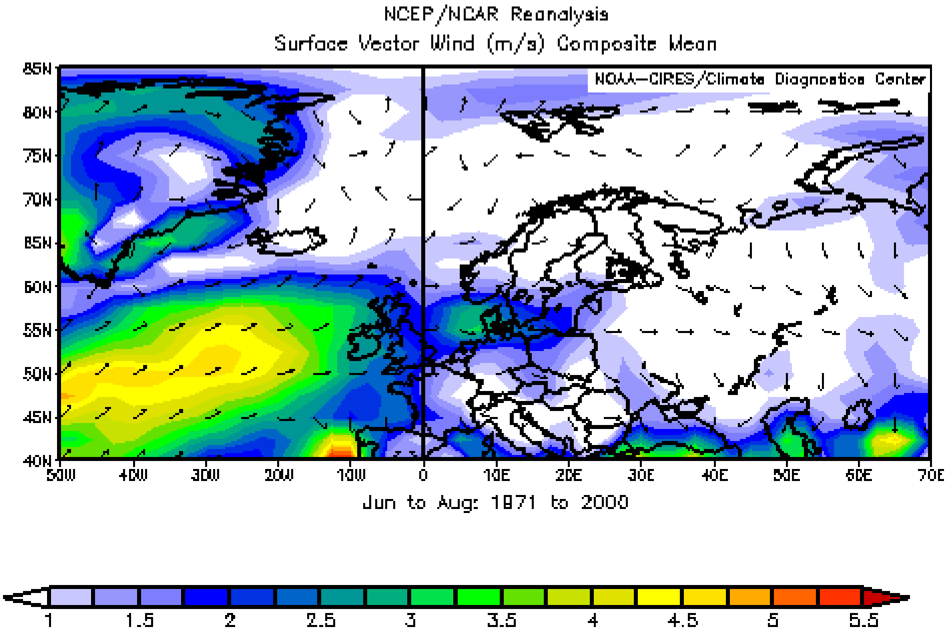


Figure 2.3. The long-term mean (1971-2000) sea level pressure (above) and wind vectors (below) in December-March.



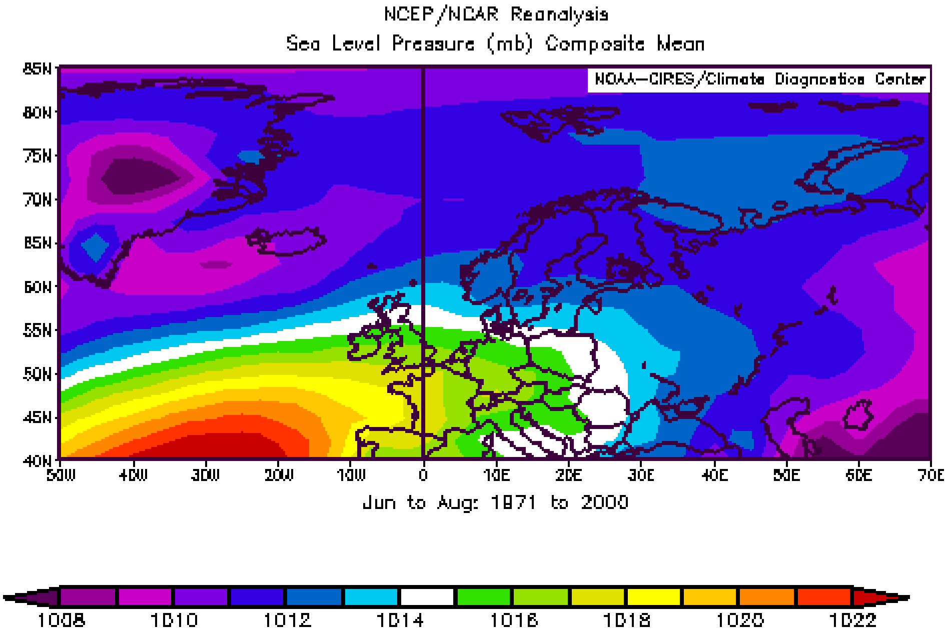


Figure 2.4. The long-term mean (1971-2000) sea level pressure (above) and wind vectors (below) in June-August.

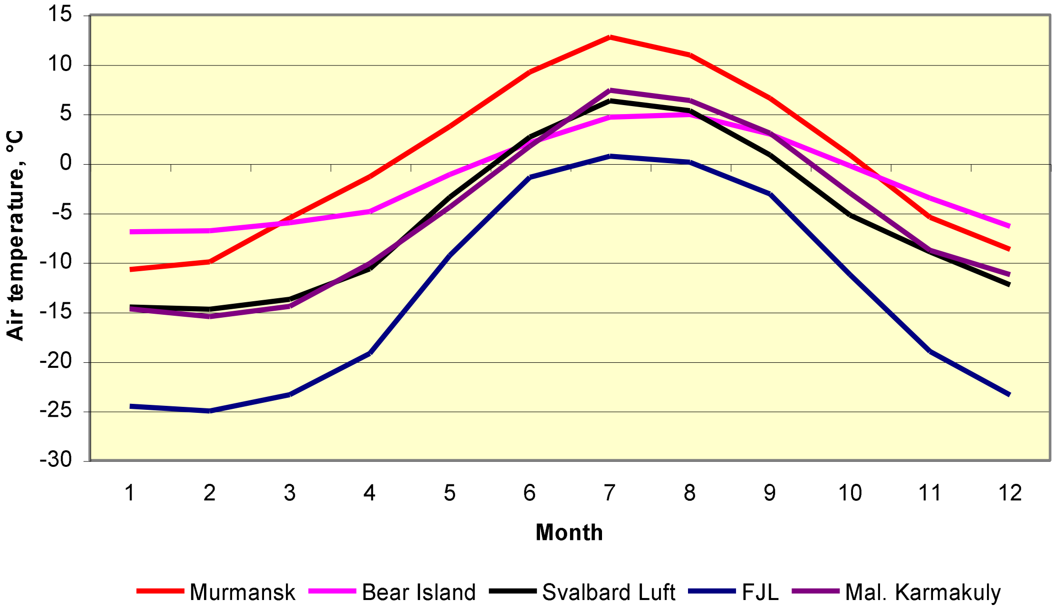


Figure 2.5. Climatic seasonal cycle of air temperature at stations Spitsbergen airport, Bear Island, Murmansk, Malye Karmakuly (southern Novaya Zemlya) and Franz Josef Land (GMO Im. E.T.).

2.3.2 Hydrographical conditions

The general circulation pattern is strongly influenced by topography. The Norwegian Atlantic Current carries the warm and salty Atlantic water northwards along the Norwegian continental shelf break outside the Norwegian Coastal Current. The current enters the Barents Sea along the Bear Island Trench where it splits into two main branches. The northern branch flows northeastwards along the Hopen Trench. The other main branch flows eastwards parallel to the coastal current towards Novaya Zemlya. This branch is called the Murmansk 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 the local wind conditions in the Barents Sea. Close to the Norwegian Coast, the Norwegian Coastal Current flow eastwards in the Barents Sea. Originating in the Baltic Sea, it carries relatively fresh water from that area as well as from the North Sea and the Norwegian rivers. During winter this current is deep and narrow, during summer it is wide and shallow. The temperature in the Norwegian coastal current has a strong seasonal signal. Cold and fresh, Arctic water arrives mainly from the Arctic Ocean, entering the Barents Sea between Nordaustlandet and Franz Josef Land and between Franz Josef Land and Novaya Zemlya. The latter branch flows westwards across the northern Barents Sea and along the eastern slope of the Spitsbergen Bank where it joins the East Spitsbergen Current. This current, which is now called the Bear Island Current, closely follows the topography around the Spitsbergen Bank, into the Storfjord Trench, before it rounds the southern tip of West Spitsbergen in a narrow zone between land and Atlantic Water. The Atlantic and Arctic water masses are separated by the Polar Front, which is characterised by strong gradients in both temperature and salinity. In the western Barents Sea the position of the front is relatively stable, but in the eastern part the position of this front has large seasonal, as well as year- to-year, variations.

Atlantic water is defined by salinity >35.0 and temperatures >3^{o}C. Between Norway and Bear Island, the temperature of this water varies seasonally and inter-annually from 3.5-7.5 °C; as a rule, both temperature and salinity decrease in the north and eastward directions (Figure 2.7). For this reason, water with salinity down to 34.95 is commonly classified as water of Atlantic origin. In the southwestern Barents Sea, Atlantic Water is normally predominant. They year-to-year temperature variability in the Barents Sea is illustrated in Figure 2.8, which shows the observed annual temperature for the last 100 year in the Kola section (Bochkov, 1982, 2005) located in the southern Barents Sea.

In ice-free Atlantic Water, the build-up and erosion of stratification are mainly determined by wind, air temperature and solar heating. During winter, strong wind and cooling can cause mixing to a depth 200-300 m. After solar radiation has begun to warm the surface layer in spring, the upper water column becomes stratified in May-June. Because solar heating of the sea surface is slow, the earliest warming is discernible only to 10-20 m depth. During the course of summer, however, further heating and mixing spread the warming to 50-60 m depth. In the uppermost ~10 m, the wind creates a homogeneous layer.

Coastal water resembles Atlantic Water except for lower salinity, <34.7. However, the temperature range is wider, especially near the surface. Unlike the other water masses in the Barents Sea, Coastal Water is vertically stratified the year round, especially along the Norwegian coast. In the shallow area near Kolgujev farther east, the stratification can be nearly broken down in winter.

Arctic water is characterised by low salinity. However, it is more easily classified by its low temperature. The core of the Arctic Water has temperature <–1.5 °C and salinity between 34.4 and 34.7. In Arctic Water, the ice cover effectively hinders wind-induced mixing in winter. In summer the pronounced layer of Melt Water hinders cooling from establishing deep convection. Thus stratification is subject to very strong control by the melting and freezing cycle of the sea ice. The rejection of brine, however, can erode the salinity gradient or, at least, the transition layer between Melt Water and the underlying Arctic Water.

The seasonal temperature signal is strong, and lags the air temperatures with 2-3 months (Figure 2.9). The maximum values are reached in September-October and the minimum values in March-April.

Processes of both external and local origin operating on different time scales govern the temperature in the Barents Sea. Important factors that influence the temperature regime are the advection of warm Atlantic water masses from the Norwegian Sea, the temperature of this water masses, local heat exchange with the atmosphere and the density difference in the ocean itself. The volume flux into the Barents Sea from the Norwegian Sea is influenced by the wind conditions in the western Barents Sea, which again is related to the Norwegian Sea wind field (Ingvaldsen *et al.,* 2004). Thus, both slowly moving advective propagation and rapid barotropic responses due to large-scale changes in air pressure must be considered when describing the variation in the temperature of the Barents Sea.

In ice-free water, winter is characterised by intense deep vertical mixing, which bring mineral nutrients to the upper layer. Come spring, the upper layer will become stratified, making a pronounced impact on the timing and development of the spring bloom. Different water masses differ strongly in terms of mixing and stratification.

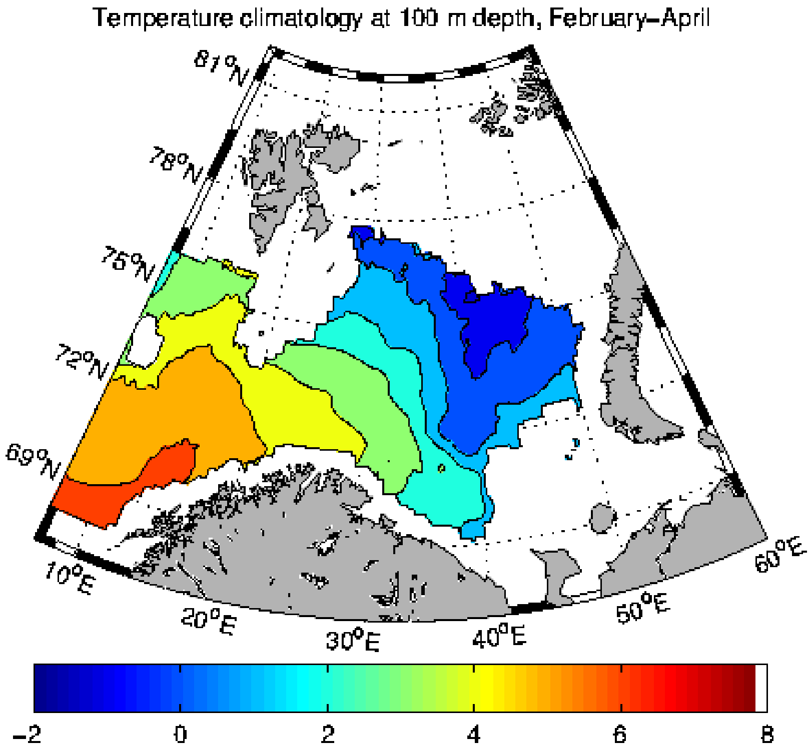


Figure 2.6. Average winter temperatures in the Barents Sea at 100 m. Based on observations in February-April for the periode 1977-1996. Please note that in any specific year the Polar front is quite sharp. This is not evident in the figure due to winter ice cover (and therebye few data in the northern areas) and interpolation effects.

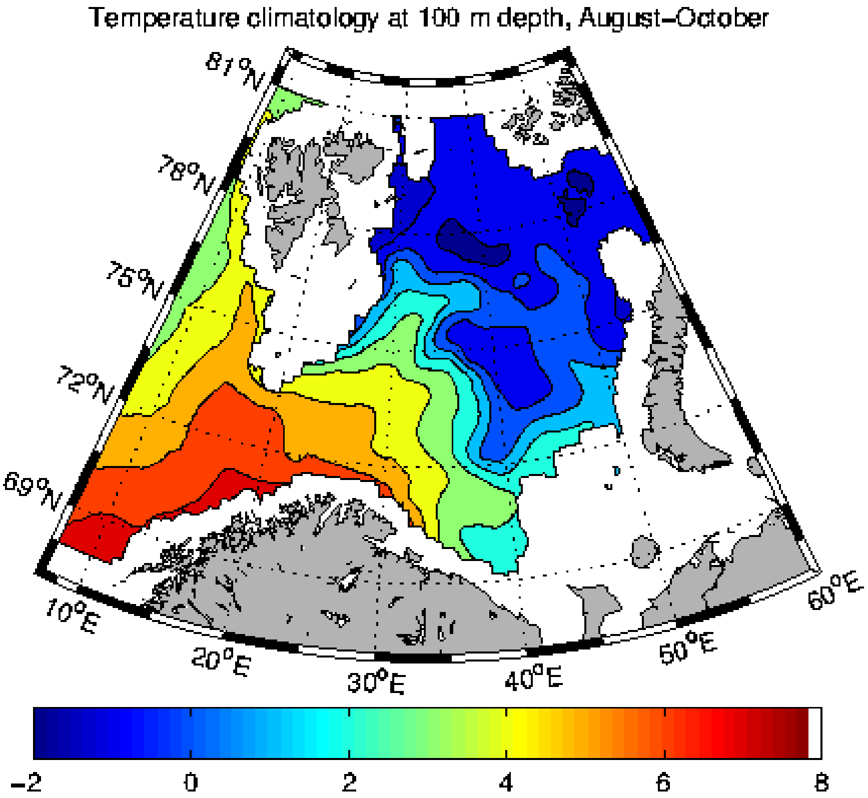


Figure 2.7. Average summer temperatures in the Barents Sea at 100 m. Based on observations in August-October for the periode 1977-1996.

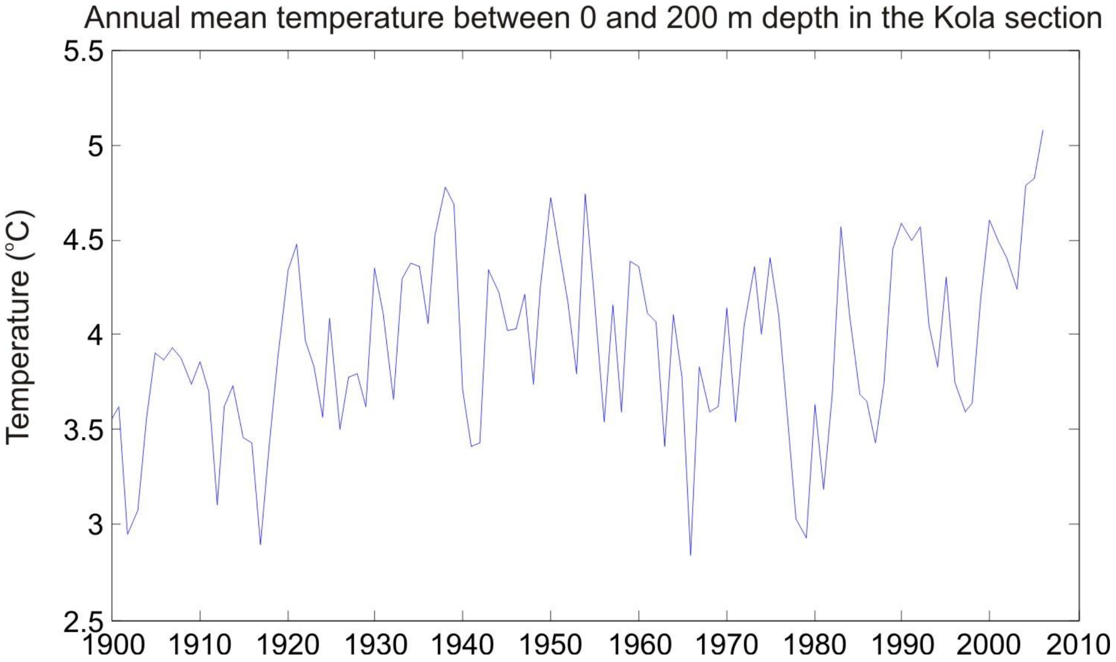


Figure 2.8. Average annual temperature between 0 and 200 m depth in the Kola section, stations 3-7 (Bochkov, 1982, 2005).

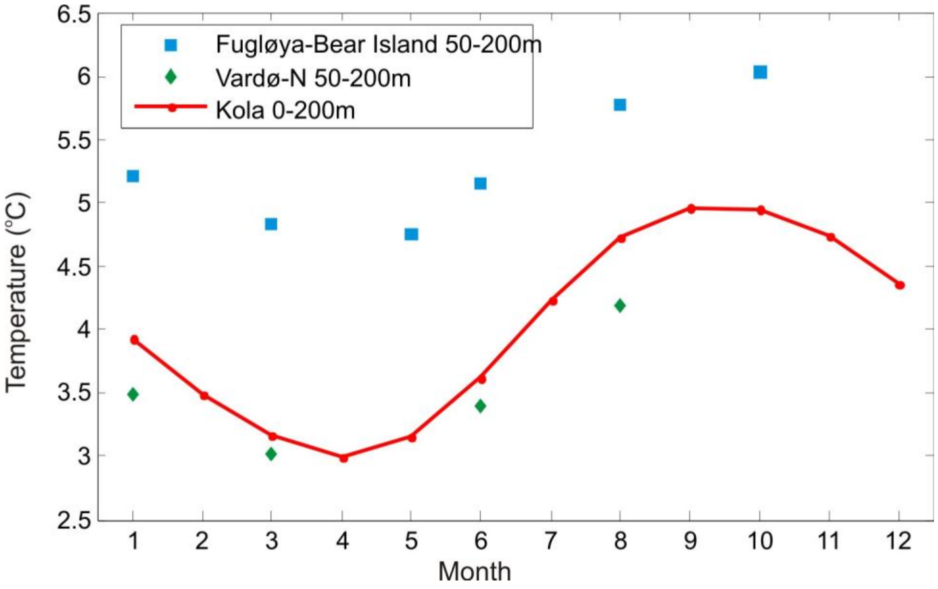


Figure 2.9. Climatic seasonal cycle in the southern Barents Sea. For Fulgøya-Bear Island and Vardø-N the ocean temperatures are between 50 and 200 m, for Kola between 0 and 200 m.

2.3.3 Currents and transports

The observed current in the section Fugløya- Bear Island is predominantly barotropic, and reveals large fluctuations in both current speed and lateral structure (Ingvaldsen et al., 2002, 2004). The inflow of Atlantic water may take place in one wide core or split in several branches. Between the branches there is a weaker inflow or a return outflow. In the northern parts of the section there is outflow from the Barents Sea. The outflow area may at times be much wider than earlier believed, stretching all the way south to 72°N. This phenomenon is not only a short time feature; it might be present for a whole month. These patterns are most likely caused by horizontal pressure gradients caused by a change in sea-level between the Barents Sea and the Arctic or the Norwegian Sea by accumulation of water and/or by an atmospheric low or high.

There seems to be seasonality in the structure of the current. During winter the frequent passing of atmospheric lows, probably in combination with the weaker stratification, intensify the currents producing a structure with strong lateral velocity-gradients and a distinct, surface-intensified, relatively high-velocity, core of inflow. During the summer, when the winds are weaker and the stratification stronger, the inflowing area is wider, and the horizontal shear and the velocities are lower. In the summer season there is inflow in the upper 200 m in the deepest part of the Bear Island Trough.

The volume transport across the Barents Sea varies with the season due to the close coupling to the regional atmospheric pressure. Numerical models forced with wind predict that south-westerly wind, which is predominant during winter, accelerates the flow of Atlantic Water into the Barents Sea, whereas the weaker and more fluctuating north-easterly wind common during summer slows the transport. The same conclusion can be reached on basis of current measurements in the exit area in the northeast Barents Sea. Monitoring since 1997 of the transport of Atlantic Water into the Barents Sea indicates a highly variable net transport that averages 1.8 Sv. The average transport of Atlantic Water into the Barents Sea for the period 1997-2006 is 2.2 Sv during winter and 1.9 Sv during summer. In years during 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 in the transport entering the western Barents Sea; at times even an outward flow.

Strong tidal currents peaking at 80-100 cm/s in spring are found on Svalbardbanken (Gjevik et al., 1994). In this area the tide induce a residual current that forms a anti-cyclonic eddy between Bear Island and Hopen, with residual current speeds up to 3 cm/s. The largest tidal amplitudes are found along the coast of Finnmark in Norway and Kola in Russia where the amplitude is up to 1.3 m. In the Hopen Trench there is a main ampidromic system (i.e. the tidal amplitude in the centre of the ampidromic system is approximately zero).

The heat transport into the Barents Sea is a combination of the inflow and the temperature of the inflowing water masses. These two factors is not necessarily linked. The reason is simply that while the temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This shows the importance of measuring both volume transport and temperature, since they not always are varying in the same manner.

Surface drifters have demonstrated a large number of mesoscale eddies in the Barents Sea, especially in the western part. Small eddies are generated both in the frontal area between the Atlantic and the Coastal Current and along the shear zone between waters flowing in and out of the Bear Island Trench, respectively. Most of these eddies are limited in time and space yet have in some cases lasted for a whole month. Also large eddies generated by the local topography are known. Examples are the cyclonic (counter-clockwise) eddy located at the Ingøy Deep and the anti-cyclonic (clockwise) eddies located at the Central and Great Banks.

Eddies prolong the local residence time for organisms that are passively advected with the currents, such as plankton and fish larvae.

2.3.4 Ice conditions

The Barents Sea is characterised by large year-to-year variations in ice conditions. The variability in the ice coverage is closely linked to the amount of the inflowing Atlantic water and the northerly winds in the Nordic Sea (Sorteberg and Kvingedal, 2006). The ice has a relatively short response time on temperature changes in the Atlantic water (1-2 years), but usually the sea ice distribution in the eastern Barents Sea responds a bit later than in the western part. Since the late 1960s there has been a decreasing trend of 3.5% per decade in sea ice extent, and in the last 3 years there has been extreme ice minimum in the Barents Sea.

2.4 Species communities

2.4.1 Phytoplankton

By E. K. Stenevik, L. J. Naustvoll and M. Skogen

The Barents Sea is a spring bloom system and during winter the primary production is low and the chlorophyll concentrations are close to zero. The timing of the phytoplankton bloom is variable throughout the Barents Sea. Primary production in this area is mainly limited by light during winter. At this time the water is mixed and nutrients are transported to the surface. In early spring, the water is still mixed and even though there are nutrients and light enough for production, the main bloom does not appear until the water becomes stratified. The stratification of the water masses in the different parts of the Barents Sea may occur in different ways. Along the marginal ice zone, the increased sun radiation during spring leads to melting of the sea ice and thereby to a thin upper layer of relatively fresh melt water. As the ice melting continues and the ice retracts northwards, the upper layer gets heated and this increases the stratification and gives the necessary conditions for the spring bloom to start in this area. In the Atlantic water masses the stratification is a consequence of solar heating of the surface waters. In the southern part close to the Norwegian coast, the bloom may start following increased vertical stability caused by lateral spreading of coastal water from the Norwegian Coastal Current (Rey, 1981). The timing and development of the spring bloom in the Barents Sea show high interannual variability, particularly in regions where there are interannual variability in sea ice cover which when it melts may cause stratification to appear earlier than if no ice were present (Olsen et al., 2003).

The dominating algal group in the Barents Sea is diatoms like in many other areas (Rey, 1993). Diatoms from the genus *Chatoceros* and *Thalassiosira* often dominate the first spring bloom. During the first spring bloom there can be very high concentrations of diatoms (up to several million cells per litre). The diatoms require silicate and when this is consumed other algal groups such as flagellates take over. The most important flagellate species in the Barents Sea is *Phaeocyctis pouchetii*.

The bloom situation (abundance and species composition) in the Barents Sea is covered on a regular basis both during the survey coverage in August-October and on the standard sections Fugløya-Bjørnøya and Vardø-Nord. During these surveys the chlorophyll concentration is measured as fluorescence 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 observations, the primary production is simulated using numerical models.

2.4.2 Zooplankton

By T. Knutsen, P. Dalpadado and E. L. Orlova

Zooplankton acts as a link between phytoplankton (primary producers) and fish, mammals and other organisms at higher trophic levels. The most abundant zooplankton species in the Barents Sea; copepods, krill and hyperiid amphipods, comprise the major part of the diet of juvenile fish, herring, capelin, and polar cod. The Arctic Front in the Barents Sea marks the boundary between the mainly Arctic zooplankton species *Calanus glacialis*, *Themisto libellula*, and the Atlantic/subarctic species *C. finmarchicus*, *Meganyctiphanes norvegica*, *Thysanoessa* spp, *Themisto* spp. The phytoplankton ice-edge bloom and the favorable production conditions at the ice edge as it retracts during summer and autumn, support temporarily large concentrations of crustaceans and other species of zooplankton that are important feed for seabirds, mammals and fish. The blooms in the Atlantic waters, though are not so intense as the ice edge blooms, occur for a longer period and therefore the total phytoplankton production is higher in these water masses. Especially the spring bloom in the Atlantic waters is of significant importance for *C. finmarchicus* reproduction. The copepod *Calanus finmarchicus* is the dominant herbivore 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 the omnivorous zooplankton, krill species (e.g. *Thysanoessa* spp.) are regarded as the most important ones. *Thysanoessa inermis* and *T. longicaudata* dominate the central and northwestern Barents Sea where as *T. rachii* is restricted to the shallow water masses in the southeast. Carnivorous zooplankton such as hyperiid amphipods (*Themisto* spp.) may feed on *C. finmarchicus* and compete with zooplankton-feeding fish as well as juvenile fish in general.

Long-term observations show pronounced year-to-year variations in biomass and abundant indices of zooplankton in the Barents Sea (Figure 2.10 and Figure 2.11). The highest average biomass during the observation period was observed in 1994 and 1995. During the period 1988 – 1992 the average zooplankton biomass was low compared to the average over the last 11 years. A comparable trend is reflected in the data from upper part of the water column (Figure 2.10, lower panel: 0-100 m). Comparing data from bottom-0 m and 100-0 m it is obvious that during this time of the year the zooplankton has initiated its seasonal vertical migration to deeper waters to overwinter. It is also apparent that smaller zooplankton (180-1000 µm size fraction), is relatively more abundant in 100- 0m depth interval, hence more important in the upper waters during this time of the year.

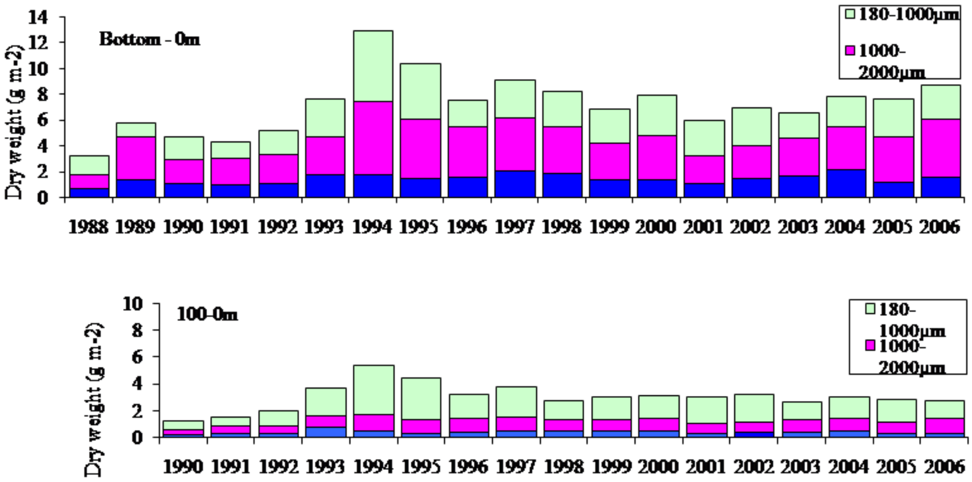


Figure 2.10. Long term development in zooplankton biomass from bottom-0 m (top) and 100-0 m (bottom) in the Barents Sea. Size fractioned samples obtained from WP2-net.

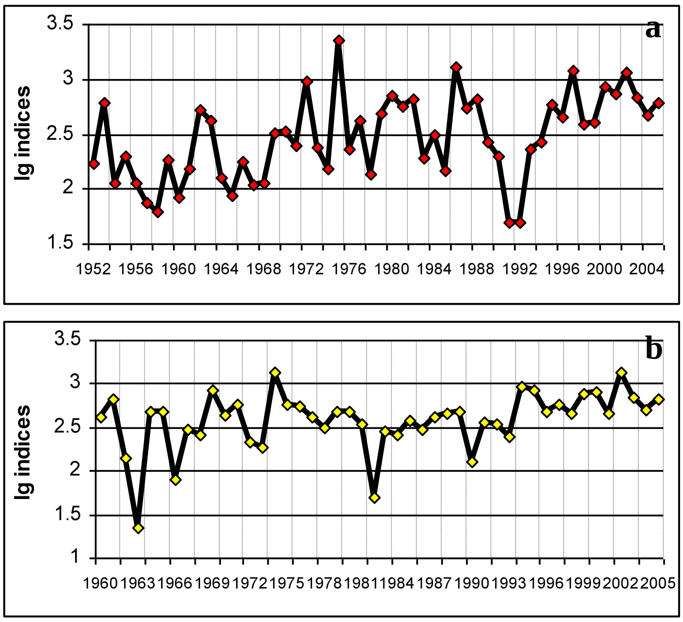


Figure 2.11. Variation in abundance indices of krill in the southern (a) and northwestern (b) parts of the Barents Sea (data from macroplankton survey conducted by PINRO).

2.4.3 Benthos

By L.L. Jørgensen, N. A. Anisimova, P. A. Liubin, I. E. Manushin and J. Sundet

2.4.3.1 Benthic community

Most of the area in the Barents Sea is covered by fine-grained sediment with coarser sediment prevailing on the relatively shallow shelf banks (<100m) or in the sub littoral zone around islands (Zenkevitch 1963). Stones and boulders are only locally abundant. The most south-westerly parts of the Barents Sea are influenced by Atlantic fauna with the diverse warm-water fauna decreasing and cold-water species increasing to the east and north. The fauna of the Barents Sea make up more than 3,050 invertebrate species (Sirenko 2001).

Because benthic communities are dependent on inputs of organic matter, characteristics of the overlying pelagic ecosystem are largely responsible for variation in the species composition in the benthos. In the Arctic, much of the annual primary production occurs during a short window in the spring ("spring bloom") that results in a seasonal pulse of short duration but high magnitude, of organic material (e.g. Sakshaug & Skjoldal 1989; Grebmeier & Barry 1991; Grebmeier et al. 1995; Wassmann et al. 1997). The amount and quality of organic material reaching the sea bottom is dependent on several interrelated factors including the timing and overall magnitude of synthesized organic matter, local advection by currents and the efficiency of grazing by herbivorous zooplankton.

In general, the fauna biomass, including the benthos, increases near the polar front and in the shallow regions and edges of the banks. A generally reduced biomass towards the west is likely due to reduced mixing of water and consequently a shortage of food. The richest infauna is found on the sandy silts and silty-sand floors. Low biomass occur at areas with impeded upwelling, in areas of low primary production (and reduced vertical flux), and areas of less suitable substrata with heavy sedimentation (e.g. inner parts of glacial fjords).

The main mass of echinoderms is found in western and central parts of the Sea, whereas the mass developments of bivalves are found in the southeastern parts of the Sea. The deeper western part is rich in echinoderms and particularly poor in polychaetes. The bivalves are considerably reduced with depth, whereas the echinoderms increase in numbers and the polychaetes remain essentially unchanged (Zenkevitch 1963).

2.4.3.2 Shellfish

Shellfish is an important part of the benthic community. However, at present, only three species are of major economical importance in the Barents Sea; the Deep sea shrimp (*Pandalus borealis*), the Iceland scallop (*Chlamys islandica*) and the red king crab (*Paralithodes camchaticus*), which was successfully introduced in the 1960s. These three species are therefore further descrbed below.

Other shellfish species of potential commercial importance are the bivalves *Serripes groenlandicus*, *Ciliatocardium ciliatum* and *Arctica islandica*, the large gastropods of Buccinidae family, as well as the Echinoderms – sea urchin *Strongylocentrotus droebachiensis* and large sea-cucumber *Cucumaria frondosa*.

Lately, the abundance of snow crab *Chionoecetes opilio* first found in the Barents Sea in 1996 has abruptly increased in numbers. At present, there are the two theories concerning the introduction of the snow crab to the Barents Sea; the transport of larvae from the northern Atlantic with ballast waters and a migration westward along the Russian north seas from the Pacific north areas. A rapid widening of its distribution area and the increase in abundance indicates successful acclimatization of this species in the Barents Sea. It may be expected that the snow crab will be one of the commercial crustacean species in this area.

2.4.3.3 *Deep sea shrimp (Pandalus borealis)*

The Deep sea shrimp (*Pandalus borealis,* also called deepwater shrimp or Northern shrimp) is distributed in most deep areas of the Barents Sea and Spitsbergen waters. The densest concentrations are found in the central part of the Barents Sea, in the Hopen Deep and Thor Iversen Bank, in depths between 200 and 350 meter (Hvingel, 2006) and near the Western Murman coast. The fishery is mainly conducted by large (>2000 GRT) trawlers, and overall annual catches have ranged from 40.000-130.000 tonnes since the early 1980s. From Russian surveys data in the period 1998-2005 the shrimp stock was estimated at 577.000-990.000 tonnes.

The shrimp mainly feed on detritus, but may also be a scavenger. Shrimp is also import as a food item for many fish species (e.g. cod, Greenland halibut and redfish) and seals.

2.4.3.4 Red king crab (Paralithodes camtschticus)

The red king crab (*Paralithodes camschaticus*) was introduced to the Barents Sea on several occations during the 1960s and 1970s (Orlov and Ivanov 1978). Since then the crab has spread to wide areas both east- and westwards and is now common in the whole southern Barents Sea from about Kanin nose in the east to about Hammerfest in west. Due to distributional patterns of juvenile crabs the stock estimates only includes crabs larger than about 70 mm carapace length, and the total stock of king crabs in the Barents Sea in 2006 were estimated to about 14 million specimens (Sundet and Sokolov 2006).

The commercial fishery of the red king crab started in the Norwegian part in 2002 and in the Russian economic waters in 2004. At present, in the Barents Sea area, the red king crab is the largest predating crustacean. Due to high abundance and feeding behavior the crab is the most important biotic factor determining the functioning of bottom communities in the southern Barents Sea. The king crab feed on a variety of prey specimens of which polychaetes, bivalves and echinoderms seem to dominate in the crab stomach analysed (Sundet *et al.* 2000). Being an introduced species it is judged to involve a potential threat for the native ecosystem. Studies so far have revealed minor impact on the bottom communities in areas where the crab have been inhabiting for decades (Anon. 2005). However, there is still a great deal of research to be done in this field before this question could be answered properly.

At present, the distribution area of the crab is from the North Cape area in Norway along the Murman coast to the Kanin Nos Peninsula in Russia. In the Russian part of the Barents Sea, the main harvesting areas of the crab are in the off shore areas.

Juvenile red king crabs are preyed upon by all common bottom feeding fishes, but as the crab becomes larger there are only a few, if any predators on the crab in the Barents Sea ecosystem. In Russian waters, the king crab is managed as a sustainable fishing stock, whilst the management regime in Norwegian waters is at the moment under consideration.

2.4.3.5 Iceland scallop (Chlamys islandica)

The Iceland scallop is widely distributed in the Barents Sea, Bear Island and Spitsbergen areas. In the Russian Economic Zone (REZ), the scallop occurs in high densities along the coast of the Novaya Zemlya and the Kola Peninsula as well as on the Goose, North Kanin and Kanin Banks. Intense fishing for the Iceland scallop (Chlamys islandica) in the Barents Sea and Spitsbergen area, was carried out through a period from 1986 to 1992 by Norwegian and foreign vessels. All scallop beds with densities of fishing interest were almost eradicated. At the most more than 4000 tonnes of scallop muscle was landed in 1987 from this area.

Near the Bear Island and in the Spitsbergen archipelago, the mollusk settlements are of no commercial importance after intensive fishery in the 1980s-1990s.Today, the main scallop harvesting are located southeast of the Bear Island, at depths of less than 100 m. In REZ, the scallop fishery has been conducted since 1987 and in 2001, the maximal annual catch were 14.000 tonnes.

The Iceland scallop is a slow growing species common in all shallow areas (< ca 150 m) both in the Spistbergen area as well as along the coastal waters of Kola Peninsula and Northern Norway (Wiborg 1963, 1970, Wiborg et al 1974, Rubach and Sundet 1987). It is usually associated with hard bottom substrate and most commonly in areas with strong currents (Wiborg 1963). 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 largely from one period to another.

2.4.4 Fish

By B. Bogstad, A. Aglen, A. V. Dolgov, K. V. Drevetnyak, H. Gjøsæter, E. Johannesen, S. Mehl, Å. Høines and O. V. Smirnov

2.4.4.1 Main fish species – stock size and fluctuations

The main demersal stocks are cod, haddock, redfish (mainly deep-sea redfish, *Sebastes mentella*), Greenland halibut, long rough dab, wolffishes and plaice. There is no analytical assessment done on long rough dab, wolffishes or plaice. The main pelagic stocks are capelin, polar cod and immature Norwegian Spring-Spawning herring. The last few years there has in addition been an increase of blue whiting migrating into the Barents Sea. There have been significant variations in abundance among these species (Figure 2.12 and Figure 2.13). These variations are due to a combination of fishing pressure and environmental variability. Until the 1970’s the redfish (*Sebastes mentella*) was an abundant stock in the Barents Sea. Due to heavily overfishing the stock declined strongly during the 1980's, and has since then stayed at a low level.

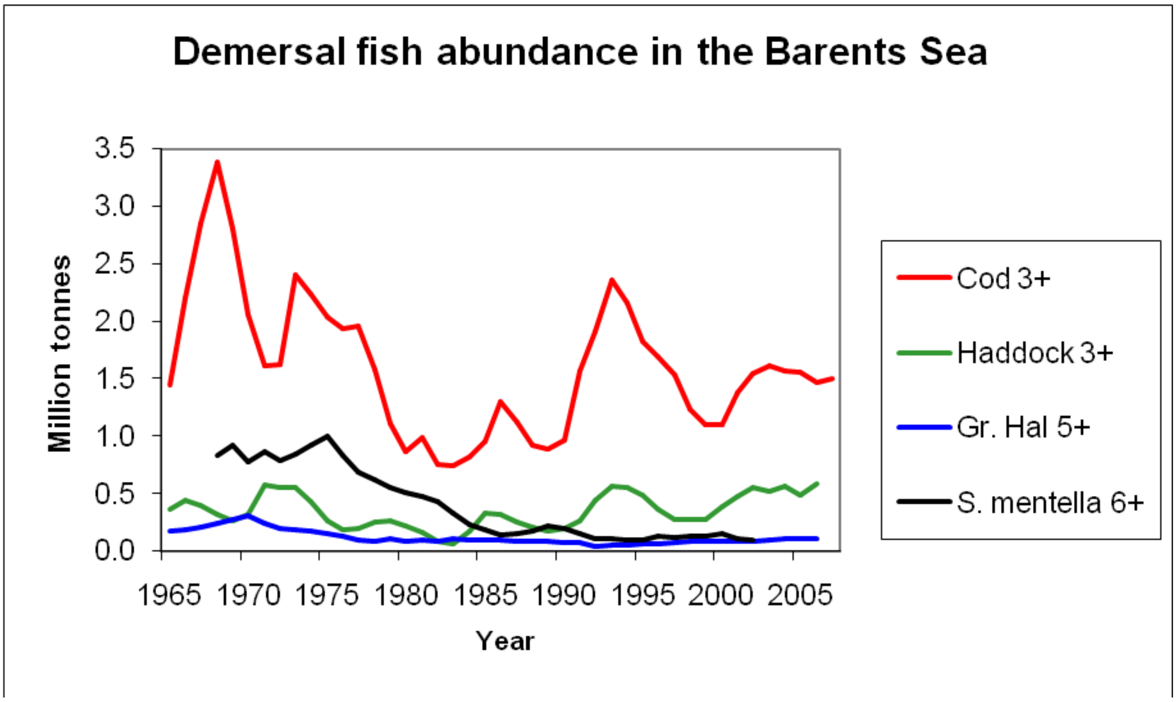


Figure 2.12. . Abundance of demersal fish species in the Barents Sea. The data are taken from; cod: VPA estimates, age 3+ (ICES, 2007); haddock: VPA estimates, age 3+ (ICES, 2007); Greenland halibut: VPA estimates, age 5+ (ICES, 2007); Sebastes mentella: VPA estimates, age 6+ (ICES, 1995 for the years 1968-1990; ICES, 2003 for the years 1991-2002).

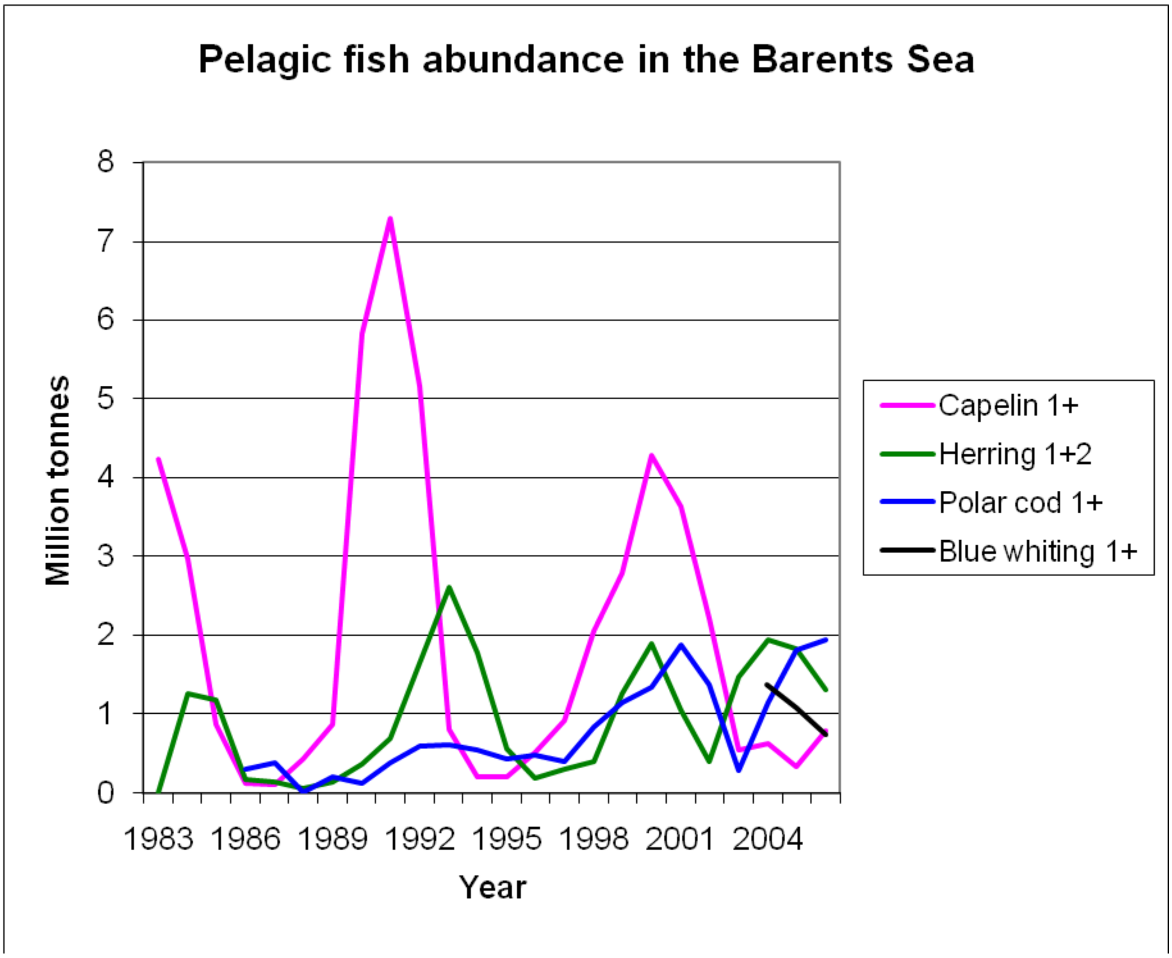


Figure 2.13. Abundance of pelagic fish species in the Barents Sea. The data are taken from; capelin: Acoustic estimates in September-October, age 1+ (ICES, 2007;, herring: VPA estimates of age 1 and 2 herring (ICES/ACFM:34, 2006) using standard weights at age (9 g for age 1 and 20g for age 2); polar cod: Acoustic estimates in September-October, age 1+ (Anon., 2006); blue whiting: Acoustic estimates in September-October, age 1+ (Anon., 2004; Anon., 2005, Anon., 2006).

2.4.4.2 Cod (Gadus morhua)

The mature cod has an annual spawning migration from the Barents Sea to the western coast of Norway. The main spawning occurs in the Lofoten area in March/April. The 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 the most important predator fish species in the Barents Sea. It feeds on a large range of prey, including the larger zooplankton species, most of the available fish species and shrimp. Cod prefer capelin as a prey, and feed on them heavily as the capelin spawning migration brings them into the southern and central Barents Sea. Fluctuations of the capelin stock have a strong effect on growth, maturation and fecundity of cod. Capelin also indirectly affects cod recruitment, as cod cannibalism is reduced in years with high capelin biomass. The role of euphausiids for cod feeding increases in the years when capelin stock is at a low level (Ponomarenko and Yaragina 1990). Also, according to Ponomarenko (1973, 1984) interannual changes of euphausiid abundance is important for the survival rate of cod during the first year of life.

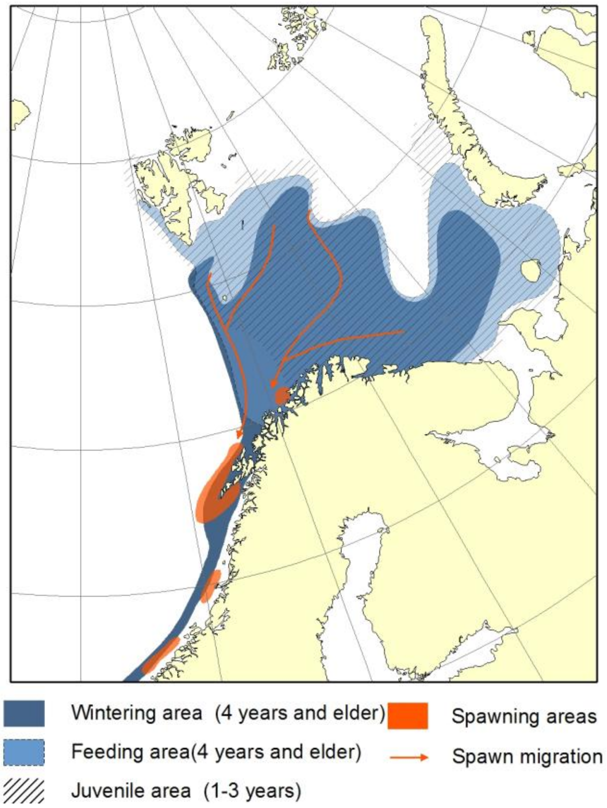


Figure 2.14. Distribution area for Northeast Arctic Cod.

2.4.4.3 Haddock (Melanogrammus aeglefinus)

Haddock is also a common species, which partly migrates out of the Barents Sea to spawn. The stock has large natural variations in stock size. Food of haddock consists mainly of benthic organisms (Zatsepin, 1939; Tseeb, 1964). Capelin is the dominant prey among fish species. Zooplankton and other fish species are of only marginal importance. There are not any clear changes in the food composition of haddock among various length groups. The total annual food biomass consumed by haddock shows large variation.

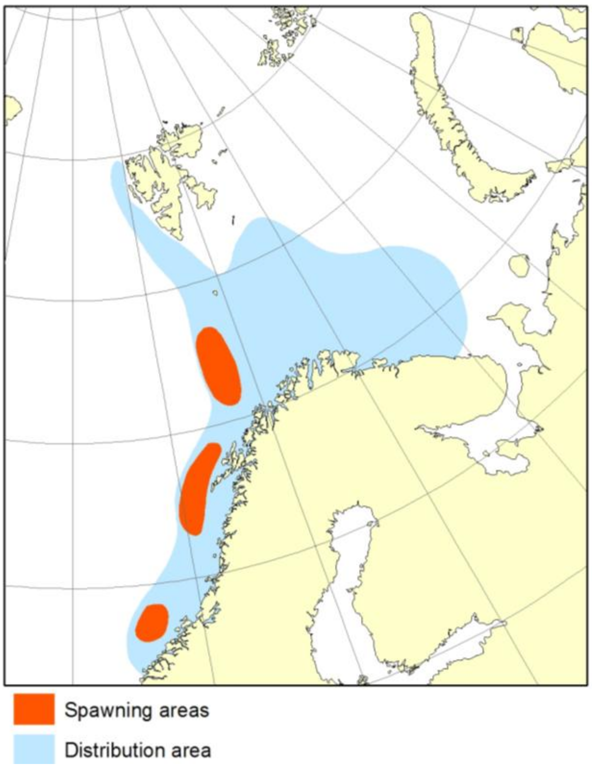


Figure 2.15. Distribution area for Northeast Arctic Haddock.

2.4.4.4 Redfish (Sebastus mentalla and Sebastus marinus)

Deep-sea redfish (*S. mentella*) and golden redfish *(S. marinus)* used to be important elements in the fish fauna in the Barents Sea, but presently the stocks are severely reduced. Young redfish are plankton eaters (Dolgov and Drevetnyak, 1995), but larger individuals take larger prey, including fish (Dolgov and Drevetnyak, 1993). Until 1990 huge amounts of redfish postlarvae filled the pelagic Barents Sea every summer and autumn. These 0-group redfish utilized the plankton production and contributed themselves to the diet of other predators. We don't know whether other planktonfeeders have taken over this niche. Since the redfish species are viviparous giving birth to live larvae, it is believed to be a strong relationship between the size and age composition of the mature stock and the recruitment. Lack of larvae and juvenile redfish in the sea is therefore a confirmation of low "spawning" stocks. On the other hand is a rebuilding of the mature stock expected to give an immediate and corresponding increase in the amounts of larvae in the sea. Fishing on these two redfish species is at present severely restricted in order to rebuild the stocks.

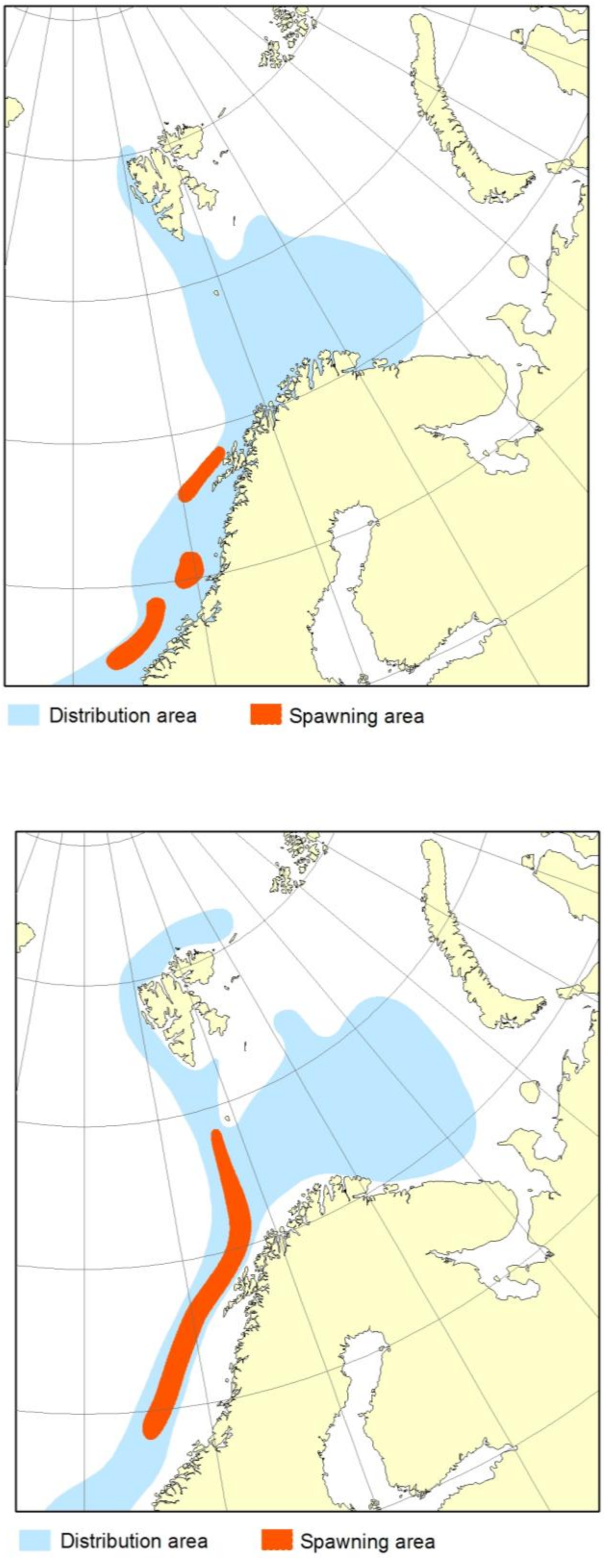


Figure 2.16. Distribution area for Deep Sea redfish (lower) and golden redfish (upper) in the Barents Sea region.

2.4.4.5 Greenland halibut (Reinhardtius hippoglossoides)

Greenland halibut is a large and voracious fish predator with the continental slope between the Barents Sea and the Norwegian Sea as its most important adult area, but it is also found in the deeper parts of the Barents Sea. Investigations in the period 1968-1990 (Nizovtsev, 1975; Shvagzhdis, 1990; Michalsen and Nedreaas, 1998; Dolgov, 2000) showed that cephalopods (squids, octopuses) dominated in the Greenland halibut stomachs, as well as fish, mainly capelin and herring. Ontogenetic shift in prey preference was clear with decreasing proportion of small prey (shrimps and small capelin) and increasing proportion of larger fish with increasing predator length. The largest Greenland halibut (length more than 65-70 cm) had a rather big portion of cod and haddock in the diet.

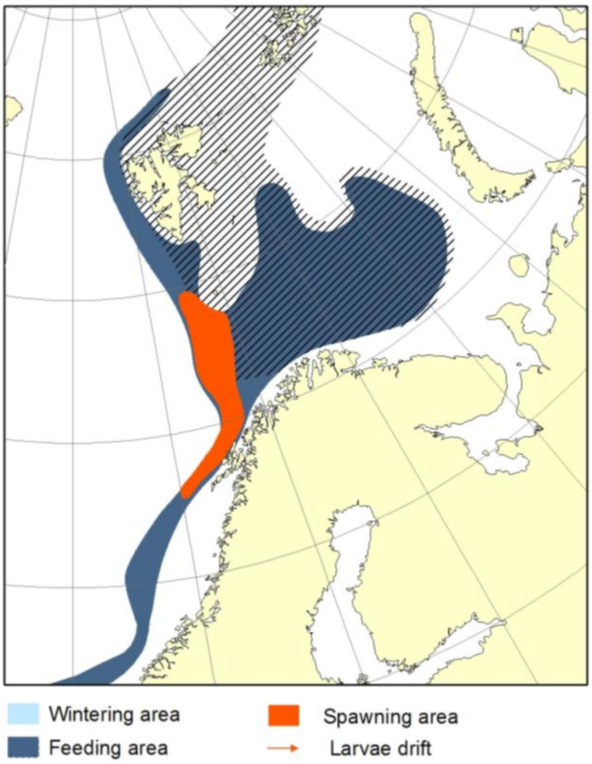


Figure 2.17. Distribution area for Northeast Arctic Greenland halibut.

2.4.4.6 Capelin (Mallotus villosus)

Capelin is a key species because it feeds on the zooplankton production near the ice edge and is usually the most important prey species for top predators in the Barents Sea, serving as a major transporter of biomass from the northern Barents Sea to the south (von Quillfeldt and Dommasnes, 2005). During summer they migrate northwards as the ice retreats, and thus have continuous access to new zooplankton production in the productive zone recently uncovered by the ice. They often end up at 78-80˚N by September-October, and then they start a southward migration to spawn on the northern coasts of Norway and Russia. During spawning migration capelin is considerably preyed on by cod. Capelin also is important prey for other predatory fishes as well as for several species of marine mammals and birds (Dolgov, 2002).

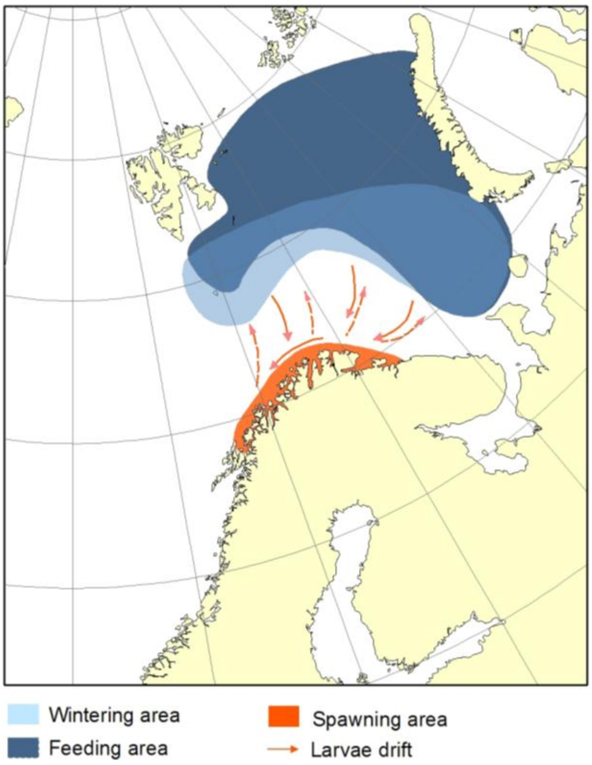


Figure 2.18. Distribution area for Barents Sea capelin.

2.4.4.7 Herring (Clupea harengus)

The herring spawns along the Norwegian western coast and the larvae drifts into the Barents Sea and some Norwegian fjords. The juveniles of the Norwegian spring-spawning herring stock are distributed in the southern parts of the Barents Sea. They stay in this area for about three years before they migrate west and southwards along the Norwegian coast and mix with the adult part of the stock. The presence of young herring in the area has a profound effect on the recruitment of capelin, and it has been shown that when rich year classes of herring enters to the Barents Sea, the recruitment to the capelin stock is poor, and in the following years the capelin stock collapses (Gjøsæter and Bogstad, 1998). This happened after the rich 1983, 1992 and 2002 year-classes of herring entered the Barents Sea. Also when medium sized year classes of herring are spread into the area there is a clear sign of reduction in recruitment to the capelin stock. In this way, the herring stock has impact both on the capelin stock (directly) and the cod stock (indirectly).

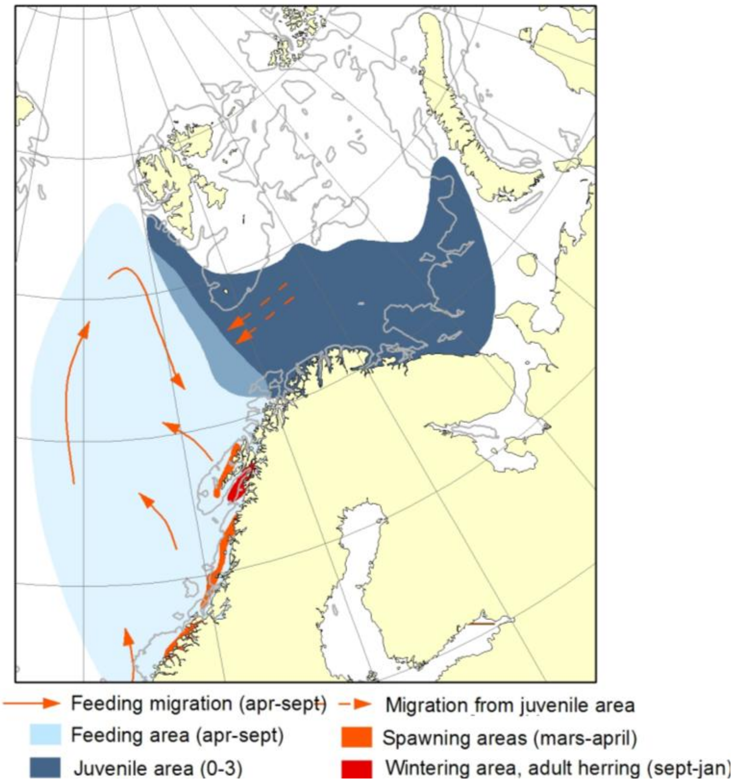


Figure 2.19. Distribution area for Norwegian spring spawning herring.

2.4.4.8 Polar cod (Boreogadus saida)

Polar cod is a cold-water species found particularly in the eastern Barents Sea and in the north. There are two spawning areas, one in the south-eastern corner of the Barents Sea and one to the east of Spitsbergen. It is an important forage fish for several marine mammals, but to some extent also for cod (Orlova *et al*., 2001). Polar cod is a semi-pelagic fish, distributed in the lower part of the water column. It is a plankton feeder, with a rather short life cycle, as fish older than 5 years are rarely found. There is little fishing on this stock.

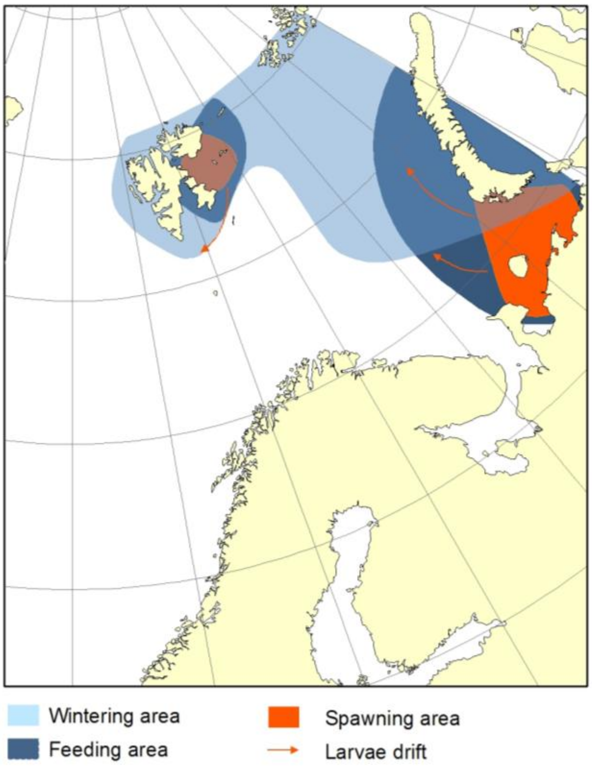


Figure 2.20. Distribution area for polar cod.

2.4.4.9 Blue whiting (Micromesisius poutassou)

The blue whiting has its main distribution area in the Norwegian Sea and Northeast Atlantic, and the marginal northern distribution is at the entrance to the Barents Sea. Usually the blue whiting population in the Barents Sea is small. In years with warm Atlantic water masses the blue whiting may enter the Barents Sea in large numbers, and the blue whiting is a dominant species in the western areas. This situation occurred in 2001, and the blue whiting has since been present in high numbers (Belikov *et al.*, 2004). The blue whiting is mainly a plankton feeder at young ages (below age 5), but changes preference towards fish during its life cycle (Belikov *et al.*, 2004). In 2004 the abundance of blue whiting were estimated to be 1.4 mill tonnes, mostly age 1-4. This made it the second most abundant pelagic plankton feeding fish this year after young herring in the Barents Sea, followed by polar cod and capelin. Historically, capelin and young herring have been the dominant plankton feeding fish stocks. In general these four species have minor overlapping distributions; with the blue whiting in the west, the herring in the south, the polar cod in the east (except for an overlapping part of the stock in the Spitsbergen region) and the capelin in the north. In southwestern areas blue whiting and herring partly overlap. However, they occupy different parts of the water column. The lack of overlapping with the other three main pelagic species, both in distribution area and water column height, indicates low interspecies competition for the local zooplankton biomass. However, the blue whiting is situated as a filter of zooplankton in their main advection pathway from the Norwegian Sea into the Barents Sea. What effect this has on the total zooplankton production, and thereby indirect on the whole ecosystem in the Barents Sea is not known.

Figure 2.21. Distribution area for blue whiting.

2.4.4.10 Saithe (Pollachius virens)

Saithe is only found in the North Atlantic. In the western part there is a small stock at Newfoundland. In the eastern part there are stocks west of Ireland and Scotland, at Iceland and the Faeroe Islands, in the North Sea and along the western and nortern Norwegian coast eastwards to the Kola Peninsula. It also occurs at Svalbard, but only in low abundances. Tagging experiments show migration between the stocks. There may be extensive migration of young saithe from the more southern part of Norwegian coast to the North Sea, and of older fish from more northern areas to Iceland and the Faeroe Islands. There are few examples of migration to the Norwegian coast.

Saithe is found both pelagic and demersal, from 0-300 m depth. It often occurs in dense concentrations, e.g. pelagic where currents concentrate prey items. The main prey items for young saithe are Calanus, krill and other crustaceans, while older fish feeds more and more on fish prey like herring, sprat, young haddock, Norway pout and blue whiting. Saithe makes both feeding and spawning migrations, and adult fish follow Norwegian Spring Spawning herring far out in the Norwegian Ocean, sometimes all the way to Iceland and Faeroe Islands. The most important spawning areas in Norwegian waters are Lofoten, Haltenbanken, the banks outside Møre and Romsdal and Tampen and the Viking bank in the North Sea. Egg and larvae drifts northwards with the currents, the 0-group settles in the shore area from the western coast of Norway to the southeastern part of the Barents Sea, and migrates to the coastal banks as 2–4 year olds.

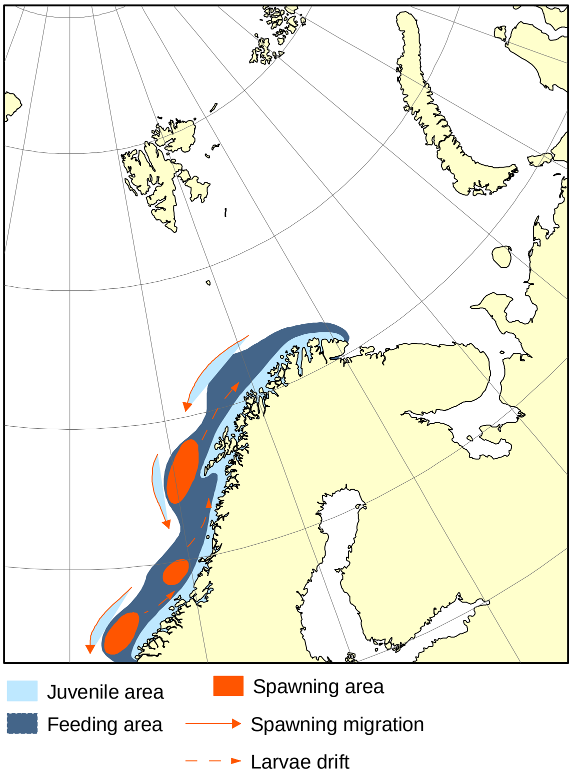


Figure 2.22. Distribution area for Northeast Arctic Saithe.

2.4.4.11 Recruitment

The recruitment of the Barents Sea fish species has a large year-to-year variability (Figure 2.23). The most important factors for this variability are variations in the spawning biomass, climate conditions, food availability and predator abundance and distribution. Variation in the recruitment of some species, including cod and herring, has been associated with changes in the influx of Atlantic waters into the Barents Sea.

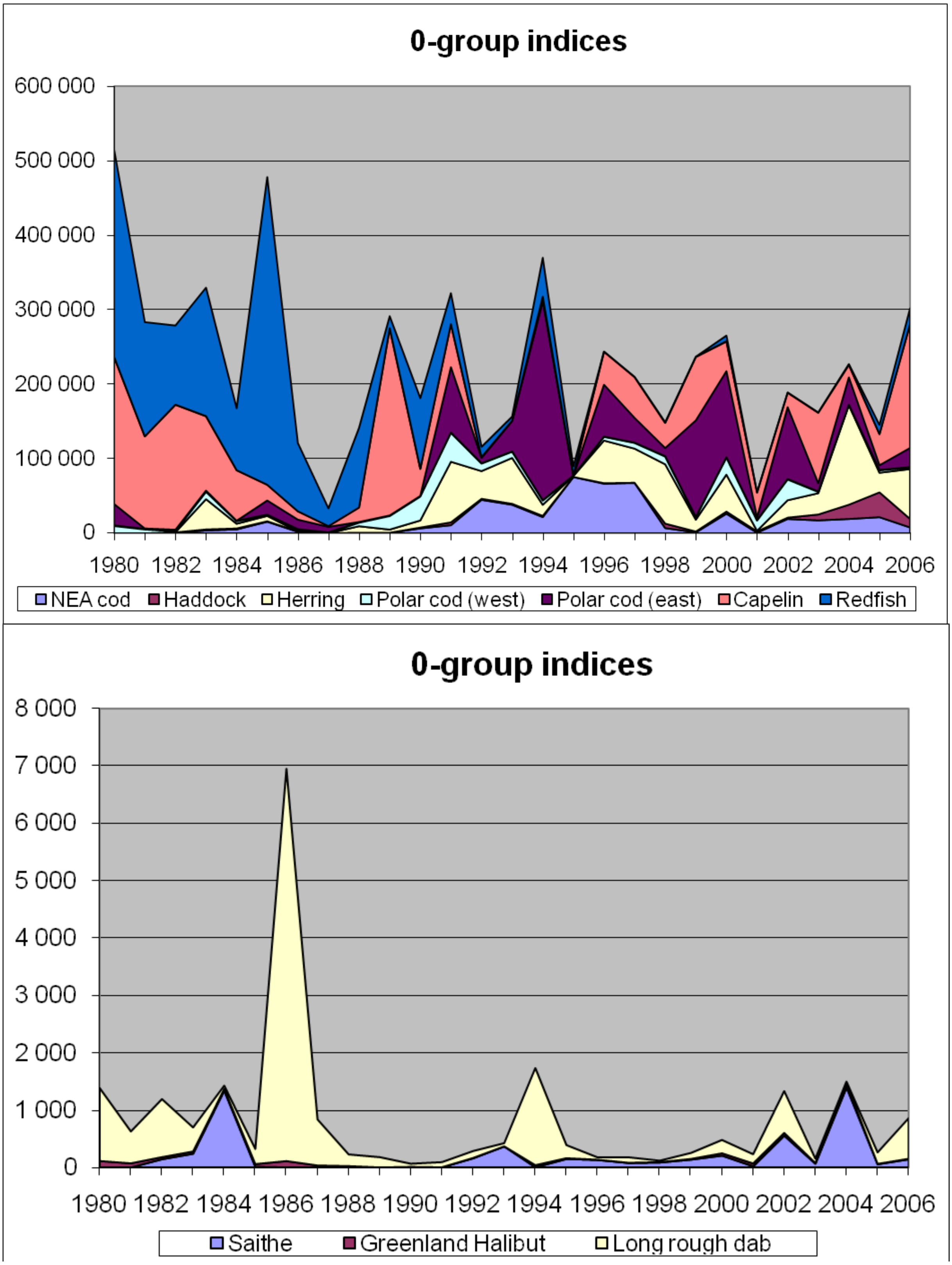


Figure 2.23. 0-group abundance indices (in millions), not corrected for catching efficiency. Please note that the vertical axes differ between the two panels.

2.4.4.12 Other fish species

The fish community in the Barents Sea is dominated by few, very abundant species, as illustrated by the log abundance -species rank plot (Figure 2.24). Recent review of taxonomy, literature and survey data gives us a list of 196 fish species from 66 families observed in the Barents Sea (Appendix), although some of the observations need confirmation. The greatest species diversity is in the following families: *Zoarcidae* (23 species), *Gadidae* (14 species), *Cottidae* (12 species), *Liparidae* (13 species), *Rajidae* (9 species), *Pleuronectidae* (9 species) and *Lotidae* (9 species). The representatives from these families account for 42% of the total number of species potentially occurring in the Barents Sea and 80 % of the species normally found in research surveys. Half of the families (34) are represented by only one species.

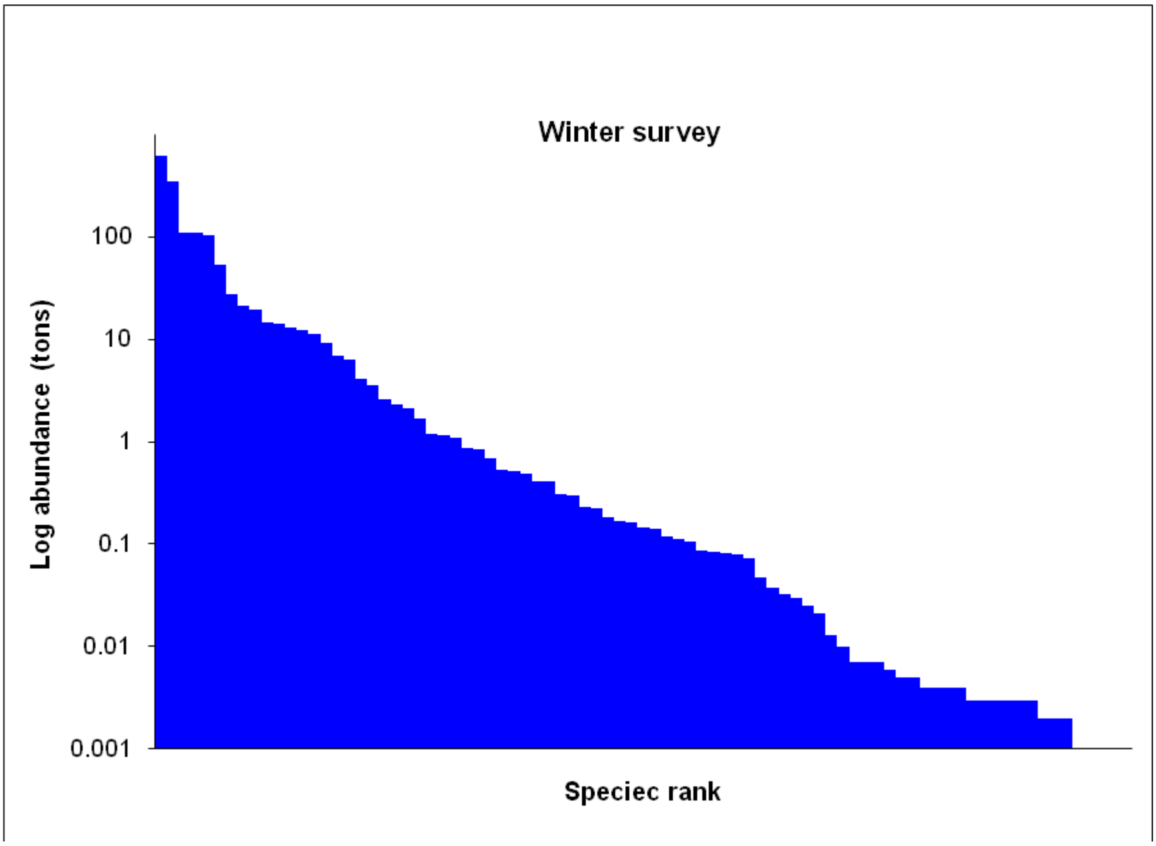


Figure 2.24. Log abundance plotted against species rank. The abundance is the total catch in tonnes from the winter bottom trawl survey run since 1981 in February.

Of the recorded species, 161 were classified according to ecological group. Almost half of the species found in the Barents Sea lives near the bottom (Figure 2.25, Appendix 1). The portions of near bottom and near bottom-pelagic species are great – 15% and 10%, respectively. Bathypelagic, neritopelagic and epipelagic species account for 6-9%. The portion of the other species (anadromous, cryopelagic, catadromous) is low (<4%). Out of the observed fish species (appendix), 157 were classified according to zoogeographical group (Figure 2.26, Appendix 1). Most of the fish species are arctic, boreal and mainly boreal – 26%, 26% and 24%, respectively. The percentage of widely distributed fish species is quite high (12%), whereas mainly arctic, arcto-boreal and southern boreal species only account for 2-6%.

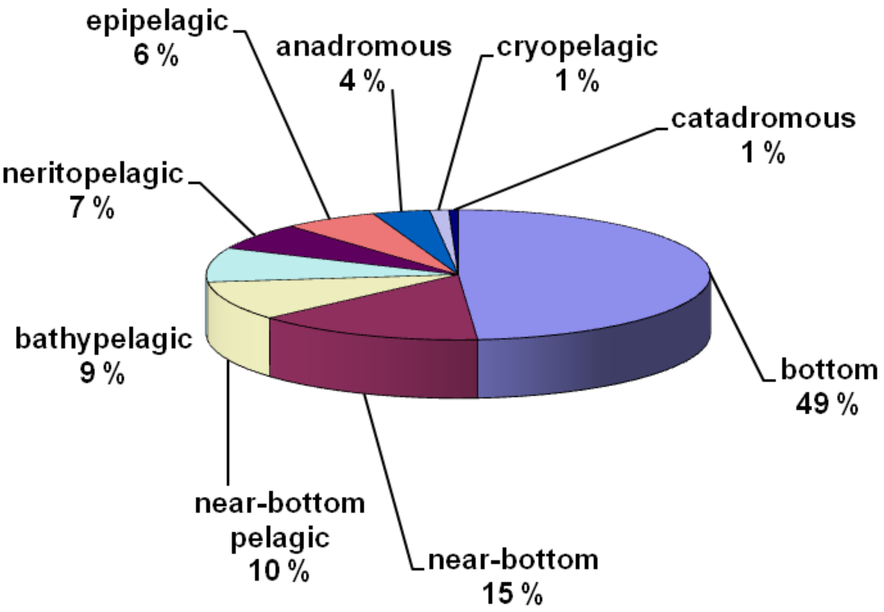


Figure 2.25. Percentage of fish species in different ecological groups.

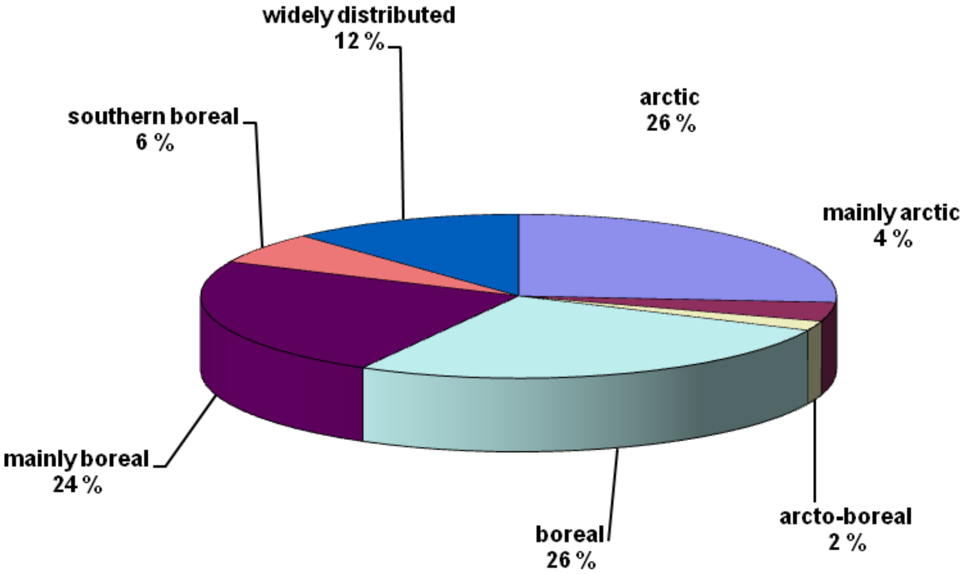


Figure 2.26. Percentage of fish species in different zoogeographical group.

From 2000-2004, the mean annual total number of species recorded on Russian survey on demersal fish in October-December has been 76. In the northern Barents Sea (ICES area IIb and the area between Spitsbergen and Franz Josefs land, southwards to approximately 76°N) the total number of species is somewhat lower than in the southern one – on the average, 49 against 58 species. In the southern part (ICES area I northward along the deep basin to Novaya Zemleya) more than 88% were mainly boreal and the portion of arctic species did not exceed 9%, in the northern one, the arctic species (58%) prevailed and the portion of mainly boreal species was 41%

In 2000-2005, the structure of the ichthyofauna varied due to variations in hydrological regime resulting from variations in transport of warm water masses. So, in the northern part of the Barents Sea, there was a reduction in the portion of arctic species while the percentage of mainly boreal and widely distributed ones increased (Figure 2.27). The same trend was found in the southern part of the Barents Sea (Figure 2.28). However, southern boreal species were absent from the catches in the southern part of the Barents Sea in 2003.

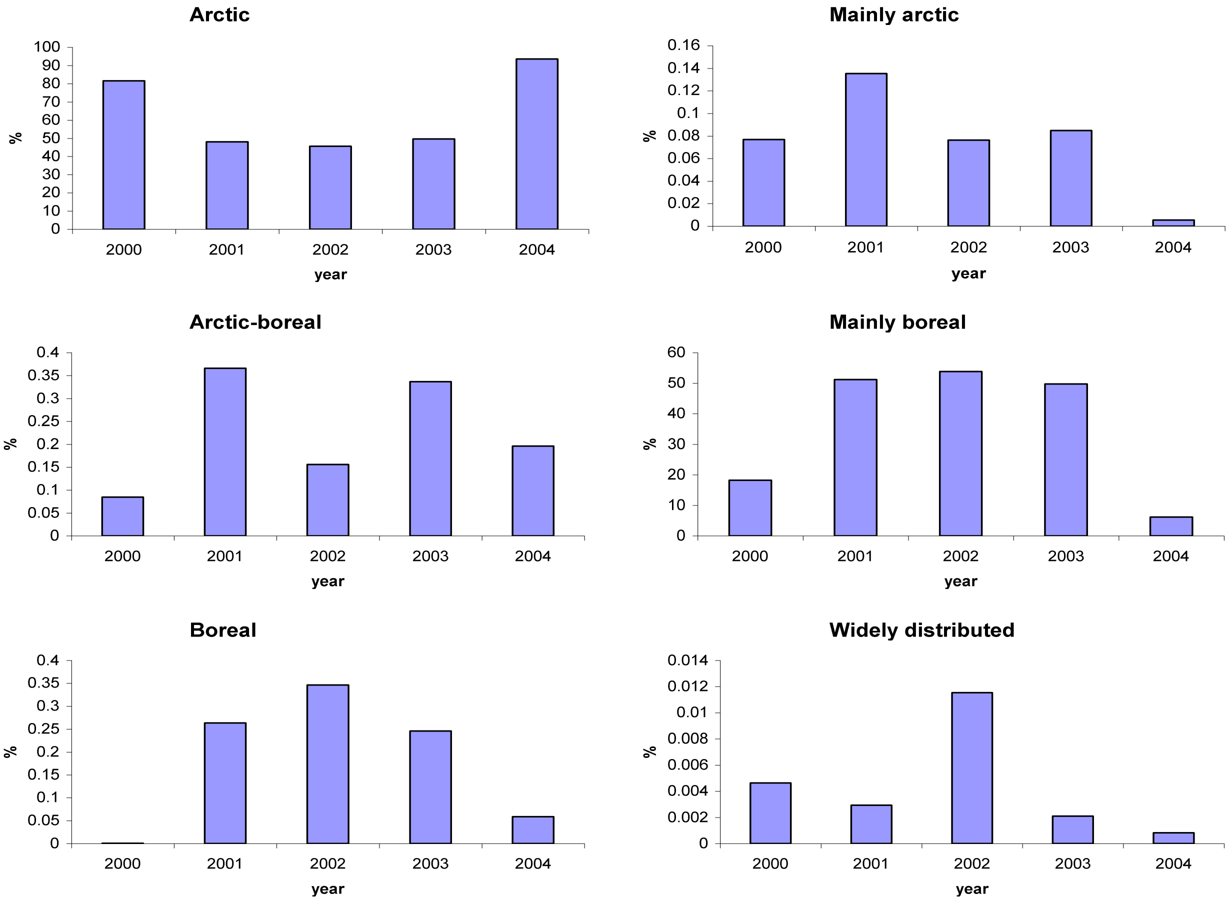


Figure 2.27. Dynamics of proportion of zoogeographical groups in the northern part of the Barents Sea in 2000-2004.

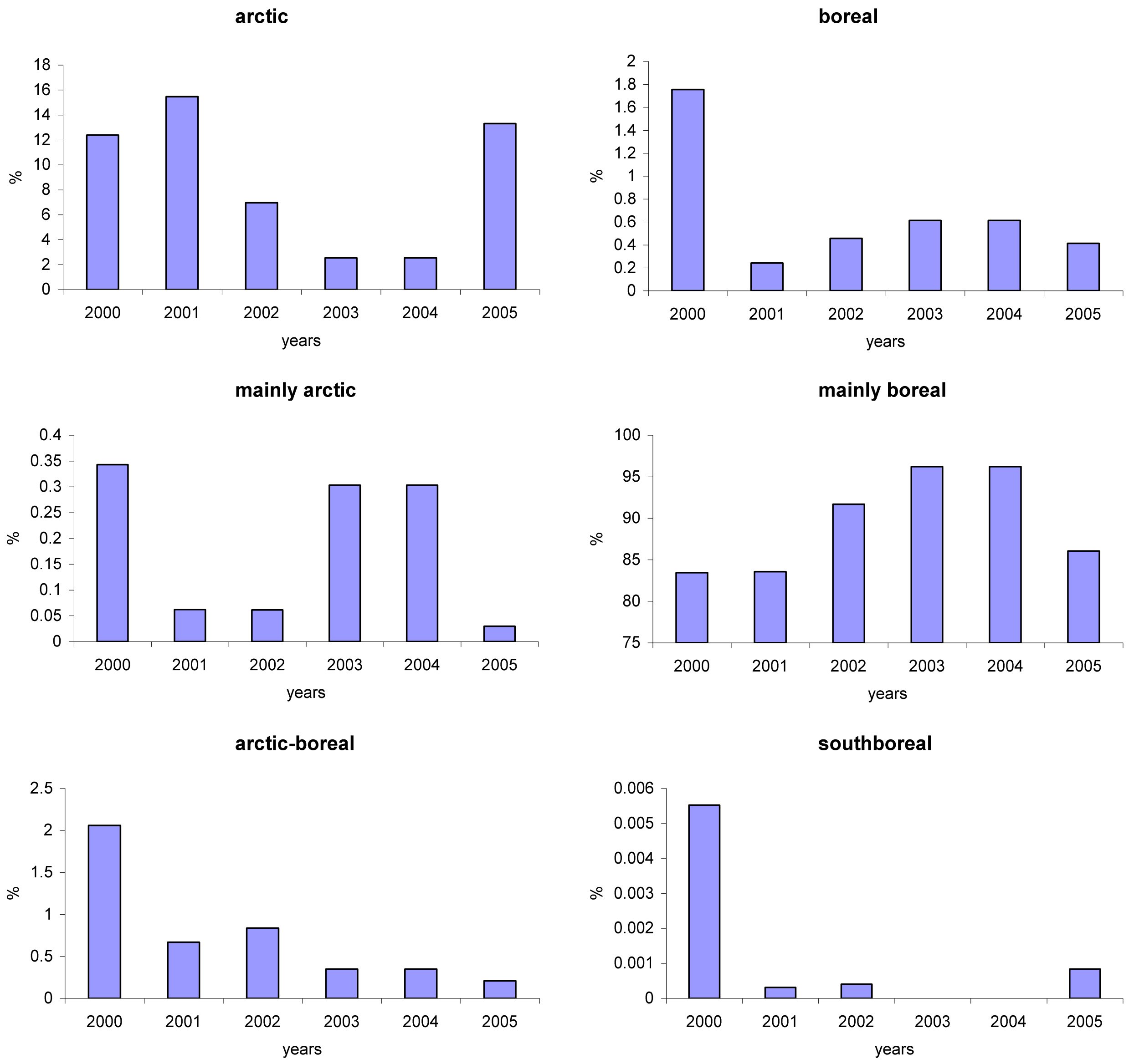


Figure 2.28. Dynamics of proportion of zoogeographical groups in the southern part of the Barents Sea in 2000-2005.

2.4.5 Marine Mammals

By V. B. Zabavnikov, M. Mauritzen, S. V. Ziryanov and N. Øien

2.4.5.1 General features

About 24 marine mammal species regularly occur in the Barents Sea, comprising 7 species of pinnipeds (seals and walruses), 12 of large cetaceans and 5 of small cetaceans (porpoises and dolphins). Some of these species have temperate mating and calving areas and feeding areas in the Barents Sea (e.g. minke whale *Balaenoptera acutorostrata*), others reside in the Barents Sea all year round (e.g. whitebeaked dolphin *Lagenorhynchus albirostris* and harbour porpoise *Phocoena phocoena*). Some marine mammals are rare, either because this is natural (like beluga whale *Delphinapterus leucas*) or because of historic exploitation (like bowhead whale *Balaena mysticetus* and blue whale *Balaenoptera musculus*). The currently available abundance estimates of the most abundant cetaceans in the north-east Atlantic (*i.e.* comprising the North, Norwegian, Greenland and Barents Seas) are: minke whales 107,205 (99% CI 83,000 - 138,400); fin whales *B. physalus* 5,400 (95% CI 3,600 – 8,100); humpback whales *Megaptera novaeangliae* 1,200 (95% CI 700 – 2,000) and sperm whales *Physeter catodon* 4,300 (95% CI 2,900 – 6,400) (Skaug *et al.* 2002, Øien 2003, Skaug *et al.* 2004). *Lagenorhyncus* dolphins are the most numerous smaller cetacean, with an abundance of 130,000 individuals (Øien 1996), but also the small and coastal harbour porpoise are numerous in this area, with an abundance of around 80 000 individuals (Bjørge and Øien 1995). Harp seals are most numerous of the seal species in the Barents Sea with approximately 2.2 million individuals. The distributions of the most common marine mammal species are given in Figure 2.29 -Figure 2.34. Marine mammals, as top predators, are significant ecosystem components. Food consumption by cetaceans in the world's oceans has been estimated to 280-500 million tonnes of total biomass (both vertebrates and invertebrates), which is between 3 and 6 times the total catch by commercial marine fisheries. In the Barents Sea, marine mammals may eat 1.5 times the amount of fish caught by the fisheries. Minke whales and harp seals may consume 1.8 million and 3-5 million tonnes of prey per year, respectively (e.g., crustaceans, capelin, herring, polar cod and gadoid fish; Folkow *et al*. 2000; Nilssen *et al*. 2000). Functional relationships between marine mammals and their prey seem closely related to fluctuations in the marine systems. Both minke whales and harp seals are suggested to switch between krill, capelin and herring depending on the availability of the different prey species (Lindstrøm *et al.* 1998; Haug *et al.* 1995; Nilssen *et al*. 2000).

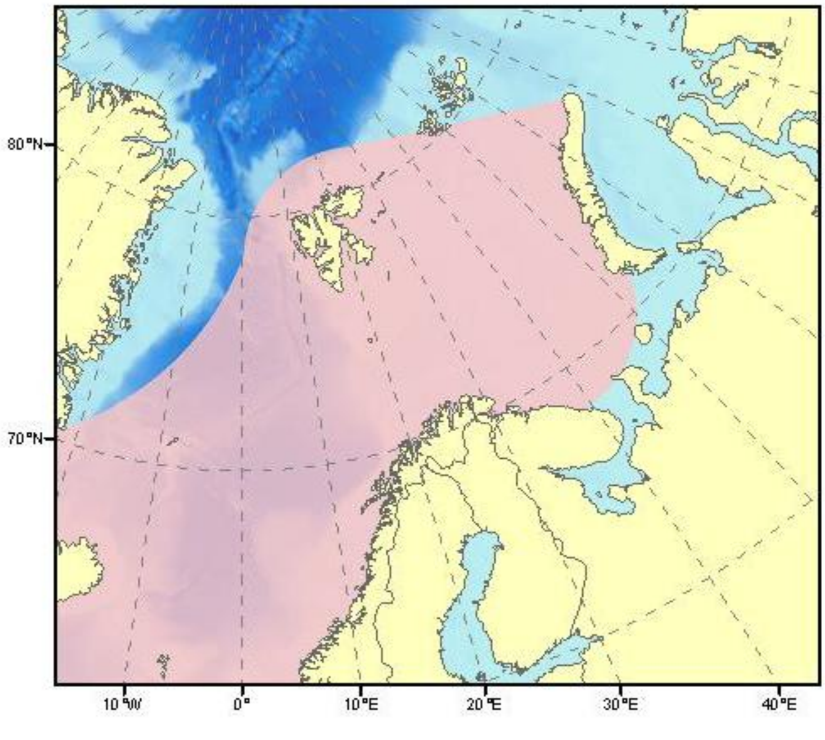


Figure 2.29. General distribution area for Minke whale.

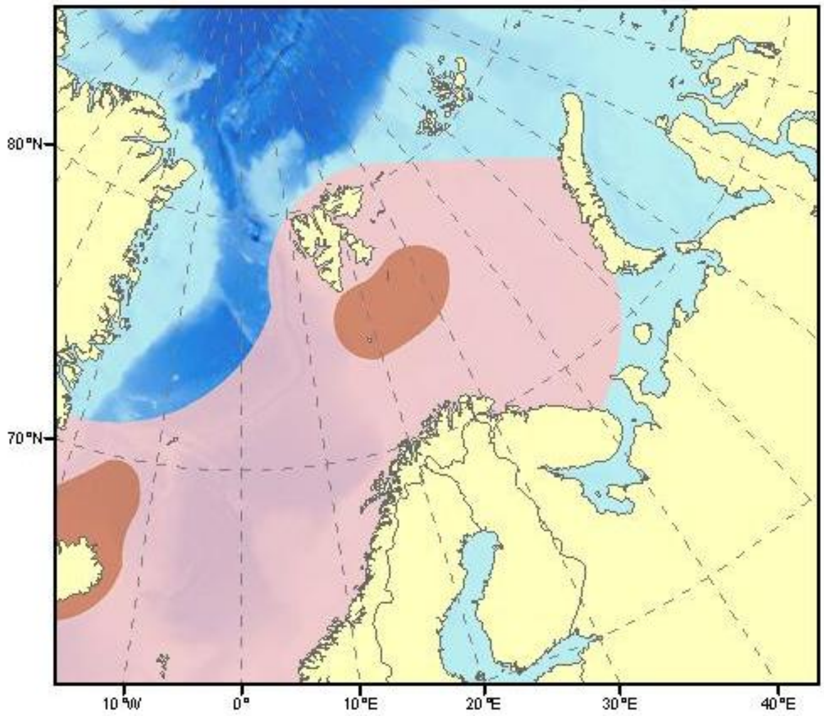


Figure 2.30. General distribution area for Humpback whale. General distribution (light red) and high density areas (dark red).

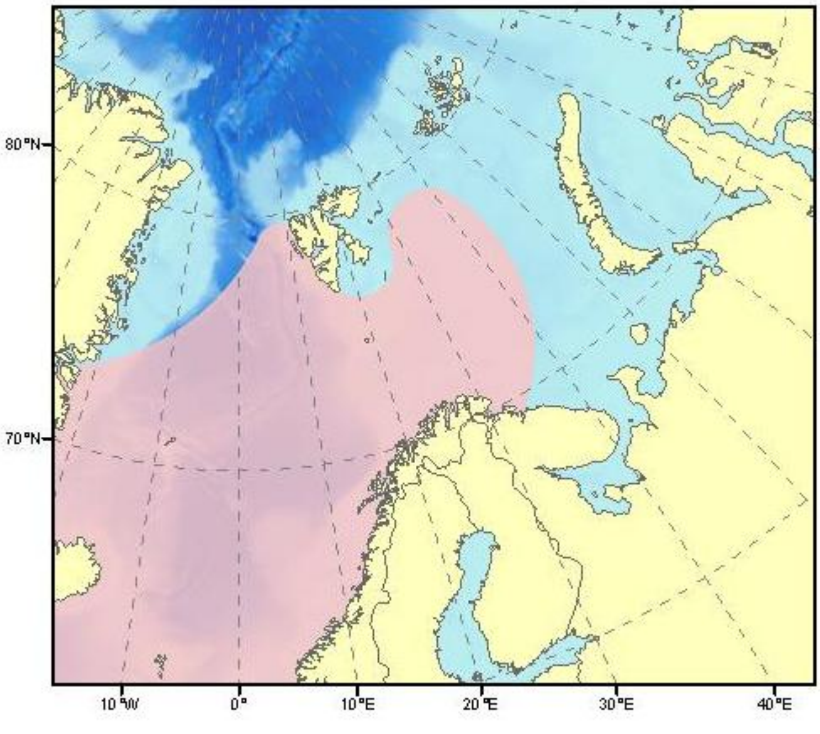


Figure 2.31. General distribution area for white-beaked dolphins.

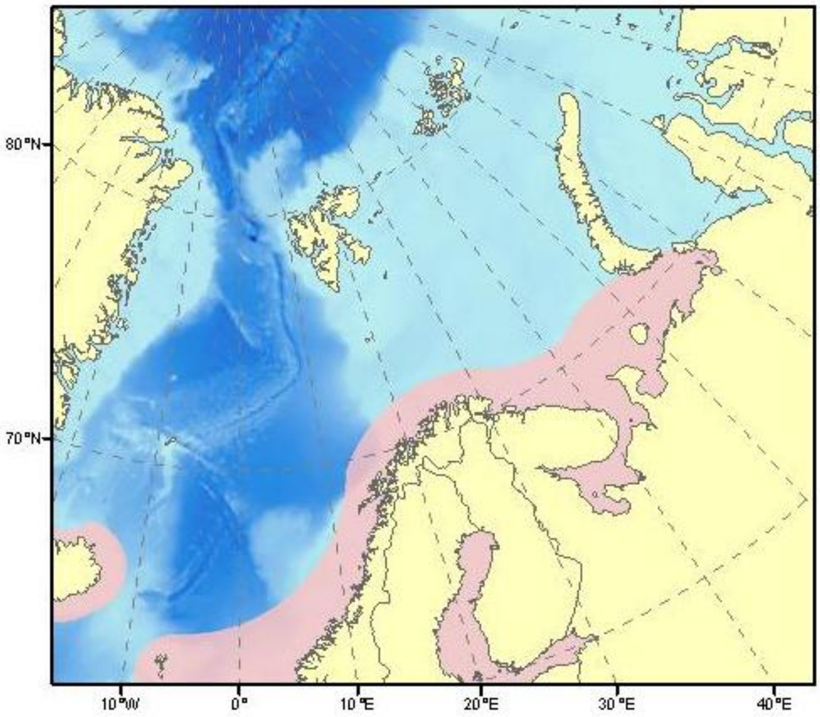


Figure 2.32. General distribution area for habour poise.

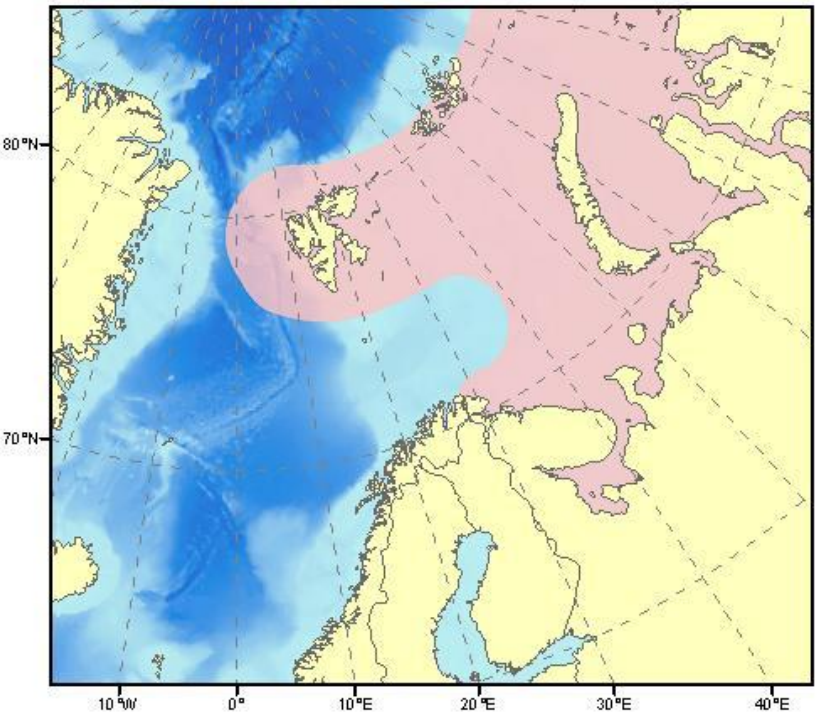


Figure 2.33. General distribution area of Beluga whale.

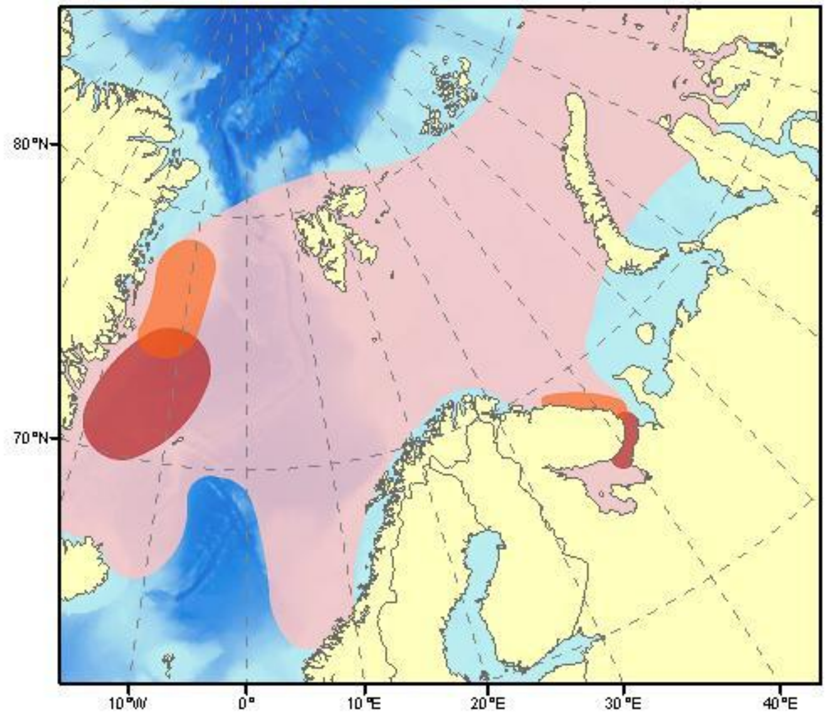


Figure 2.34. General distribution area of Harp seal. General distribution (light red), whelping area (dark red) and moulting area (orange).

2.4.6 Seabirds

By V. B. Zabavnikov, M. Mauritzen, S. V. Ziryanov and N. Øien

The Barents Sea holds one of the largest concentrations of seabirds in the world (Norderhaug *et al.*, 1977; Anker-Nilssen *et al.*, 2000). About 20 million seabirds harvest approximately 1.2 million tonnes of biomass annually from the area (Barrett *et al.*, 2002). About 40 species are thought to breed regularly around the northern part of the Norwegian Sea and the Barents Sea. The most typical species belong to the auk and gull families. There are about 1,750,000 breeding pairs of Brünnich's guillemot (*Uria lomvia*) in the Barents region. They feed on fish, particularly polar cod, and other ice fauna species. The population of common guillemots (*Uria aalge*) is about 140,000 breeding pairs. Capelin is the most important food source all year round.

There are thought to be more than 1.3 million pairs of little auk (*Alle alle*) in the Barents Sea. It is found in the area throughout most of the year and many probably winter along the ice margin between Greenland and Spitsbergen and in the Barents Sea. Small pelagic crustaceans are the main food for this species, but they may also feed on small fish.

The black-legged kittiwake (*Rissa tridactyle*) breeds around the whole of Spitsbergen, but like the Brünnich's guillemot it is most common on Bear Island, Hopen and around Storfjorden.

Its most important food items in the Barents Sea are capelin, polar cod and crustaceans. The breeding population seems stable, comprising 850 000 pairs in the Barents region. The northern fulmar (*Fulmarus glacialis*) is an abundant Arctic and sub-Arctic species living far out at sea except in the breeding season. It lives on plankton and small fish taken from the surface. The population estimates are uncertain, but high (100,000 – 1,000,000 pairs). The Atlantic puffin (*Fratercula arctica*) is the most abundant seabird on the mainland and in the Norwegian Sea, but may also breed on Bear Island and on Spitsbergen.

2.5 Ecological relations

By K. Drinkwater, B. Bogstad, A. V. Dolgov, Å. Høines, N. V. Muchina, E. L. Orlova and G. Ottersen

2.5.1 Marine Ecosystem Responses to Climate Variability

Climate variability occurs on a variety of time scales. On multidecadal scales, the waters in the Barents Sea were relatively cold in the late 19th century and early part of the 20th, warm from the 1920s to the 1950s, cool through the 1960s to the 1980s and warm during the last decade or more. These changes are due to a combination of atmospheric heating and cooling and variability in both the volume and temperature of the incoming Atlantic water (Ingvaldsen et al., 2003). Associated with warm and cool periods, sea-ice coverage has contracted and expanded, respectively. Interannual variation in the position of the ice edge in any particular month is about 3 to 4° of latitude. Recently sea-ice coverage has been near its minimal value, although the 1930s was another period of low ice coverage. At interannual to decadal time scales, ocean temperature variability is correlated with the NAO with higher temperatures generally associated with the positive phase of the NAO (Ingvaldsen et al., 2003). The higher correlation after the early 1970s is attributed to the eastward shift in the Icelandic Low (Ottersen et al. 2003).

With the warming in the 1920s and 1930s, cod appeared in high abundance on Bear Island Bank, resulting in the reestablishment of a cod fishery there after an absence of almost 40 years (Blacker, 1957). Cod also spread northward into the area off West Svalbard with sufficient abundance to support a fishery (Beverton and Lee, 1965). Cod as well as haddock moved eastward reaching Novaya Zemlya by 1929-1930 (Cushing, 1982). There was a distributional shift in spawning with proportionately more cod spawning in the northern regions of Norway (Lofoten and Finnmark) compared to southern Norway at Møre (Sundby and Nakken, 2004). During the colder periods before and after the warm period, the percent spawning at Møre was much higher. There is a suggestion that the cod might also have spawned earlier during the warm period, based upon timing of the ratio of the weight of the roe to the weight of the cod at Lofoten, (Pedersen, 1984). However, since younger cod spawn later (Pedersen, 1984), the suggested later spawning of the population during the colder period might equally be explained by fishing down of the older cod.

The stock size of Arcto-Norwegian cod in the Barents Sea and offshore Norway peaked in the 1930s and 1940s (Hylen, 2002). Catch per unit effort (CPUE) also was significantly higher in the period 1925-1960 than in the periods before or since, consist with an increase in abundance levels at that time (Godø, 2003). While this change coincided with the rapid development of the trawl fishery and increasing fishing efficiency cannot be ruled out as a contributor to the increased CPUE, recruitment was higher during the warm period than the subsequent cool period (Godø, 2003). High recruitment is believed to be, in large part, a result of greater food availability (Sætersdal and Loeng, 1987; Ottersen and Loeng, 2000). The mean weight of the cod in Lofoten rose rapidly in the 1920s into the early 1930s and remained high before starting a general decline in the 1960s. The increase in weight between the pre-1920s period and 1930s-1960s was over 50%.

The capelin feeding migration from the northern coast of Norway to the Arctic Front and beyond has tended to spread farther north and east in the Barents Sea during warm periods and contract during cold periods (Vilhjálmsson, 1997). In the 1920s, the 0-group and age 1-3 herring, which typically occupy the western Barents Sea, pushed farther eastward as evidenced by the development of a herring fishery along the Murman coast of Russia, where previously this species was almost unknown (Beverton and Lee, 1965). Particularly large catches were observed in the 1930s (Cushing, 1982). Also in the 1930s, Atlantic salmon, cod and herring appeared in the Kara Sea and haddock catches were recorded in the White Sea for the first time (Cushing, 1982).

The changes to the marine ecosystem were not limited to fish. Extensive Russian studies revealed a retreat of benthic species in the Arctic and an increase in the number of boreal species along the Murman coast, such that the relative number of boreal species doubled between the period prior to and during the peak of the warming (Nesis, 1960). Gastropods (*Gibbula tumida*, *Akera bullata*), hermit crabs (*Eupagurus bernhardus* L.) and cockles (*Cerastoderma edule* L.), all species normally associated with Atlantic waters, were reported along this coast for the first time in the 1930s (Cushing, 1982). Benthic ecosystem changes were also recorded to the west and southwest of Svalbard. Comparing the benthos prior to 1931 with that of the 1950s indicated that Atlantic species had spread northward by approximately 500 km (Blacker, 1957). This was attributed to an increased influence of Atlantic waters and is consistent with an increase of the warm north-flowing West Spitzbergen Current noted by Brooks (1938).

2.5.2 Plankton and fish

The Barents Sea is a nursery area for several commercial fish species that feed on zooplankton. Important groups are young herring, 0-group capelin, cod, haddock, saithe and redfish. In addition there is now a tendency for other fish species to become more important, extending their distribution in the Barents Sea. Such species are blue whiting and sandeel. This means increased competition for food and a suggested higher predation on zooplankton.

2.5.2.1 Zooplankton-capelin

One of the most important plankton consumers in the Barents Sea is capelin. From the early 1980s till today the capelin stock has fluctuated significantly, and it is interesting to observe the importance of this variability for the measured zooplankton stock in August-September throughout the same period. Even if many factors influence the abundance and zooplankton production, it seems to be close to an inverse relationship between capelin and zooplankton biomass (Figure 2.35). When the capelin stock was at a minimum in 1994-1995, a maximum in zooplankton abundance was observed.

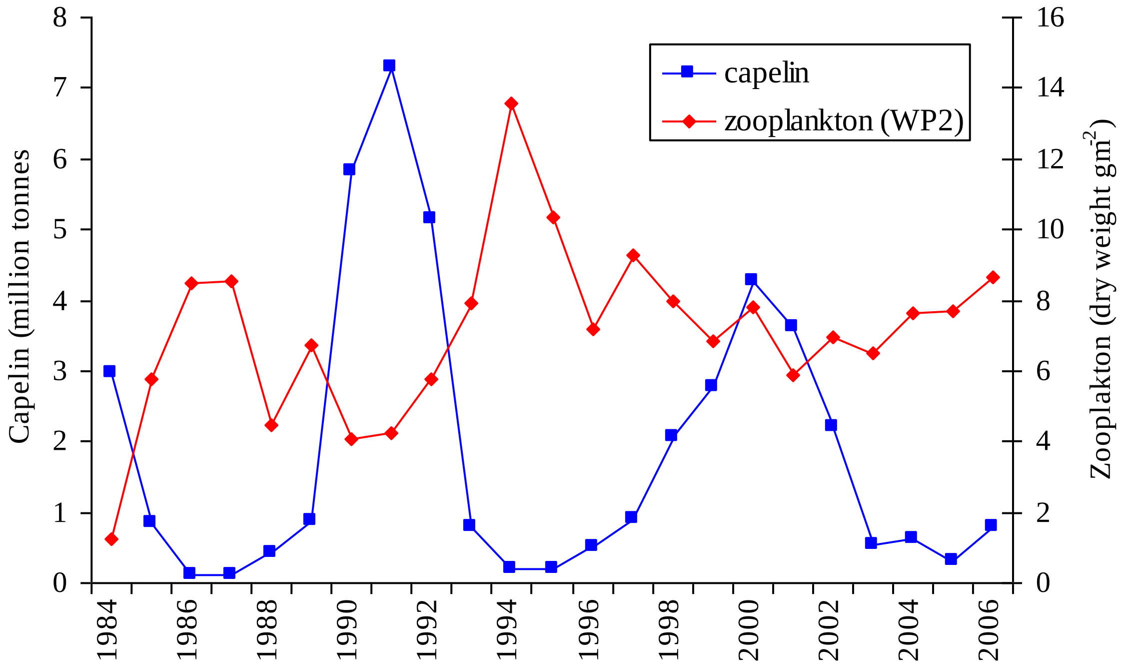


Figure 2.35. Annual fluctuations in zooplankton biomass and size of capelin stock in the Barents Sea.

2.5.2.2 Zooplankton, capelin and cod interactions

Cod (*Gadus morhua*) is a major predator in the Barents Sea ecosystem. Growth of young Northeast Arctic cod in the Barents Sea has shown strong fluctuations. The mean length of age 3 cod in the Norwegian winter bottom trawl survey has varied between 28 and 42 cm during the period 1984-2007 (ICES, 2007). Correspondingly, the mean weight at age 3 in this survey has varied between 200 and 800 g. Thus, in order to give predictions of cod stock biomass, it is important to predict size at age and not only abundance at age.

Strong relationships between cod, capelin and euphausiids have been demonstrated e.g. by Drobysheva and Yaragina (1990). Predation on euphausiids by cod decreased the food supply for capelin and reduced the capelin feeding and possibilities for stock recovery. At the same time predation on euphausiids by capelin reduces the food supply for both adult and juvenile cod.

Individual growth in fish depends on density dependent factors such as availability of prey. However, growth is also dependent on a series of processes (feeding, metabolism, excretion etc.), which are controlled by temperature (Ottersen *et al*. 2002; Michalsen *et al.*, 1998).

2.5.3 Benthos and fish

Bottom animals make up parts of, or the total diet, of several fish species. The last 20 years has been subject to an extended sampling of stomachs from cod and haddock (Jiang and Jørgensen, 1996). Preliminary evaluation of these data shows that the diet of cod (7-11 years old) when eating bottom animals (less that 10 % of total stomach content) varies little with area (Figure 2.38) and constitute mainly of crustaceans such as Spirontocaris spinus (prawn) and Hyas (decorator crabs), while in the northern areas the amphipods Tmetonyx (amphipod) while Pagurus bernhardus in the eastern and western areas functions as an additional prey species.

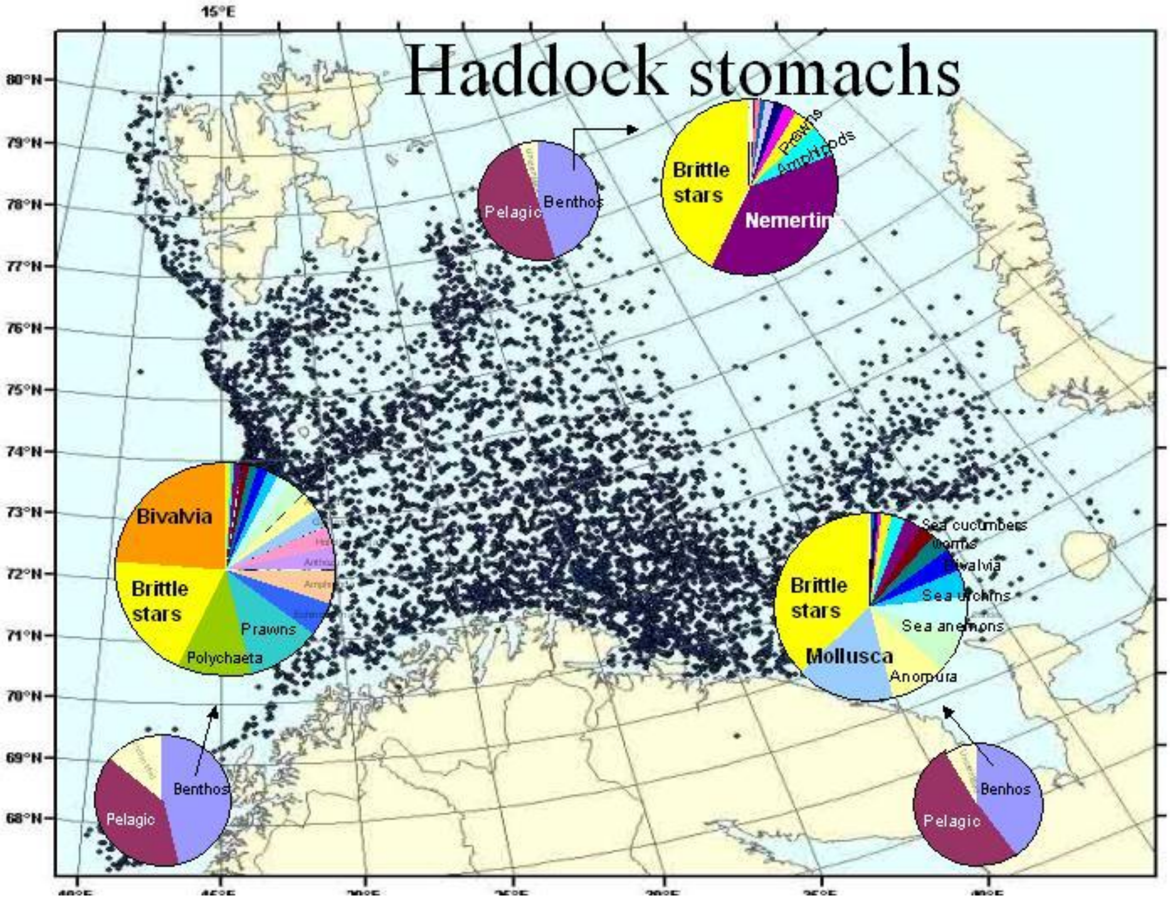


Figure 2.36. The stomach content (small reddish blue circles) of haddock (3-11 years old) and detailed information (yellow orange circles) on what animal groups (approximately 50% of the total stomach content) that constitute bottom species.

The diet of haddock (3-11 years) when eating bottom animals in the northern Barents Sea (approximately 50% of the total stomach content) was mainly made up by brittle stars (unidentified) (Figure 2.36). Additionally main prey species was Rhynchocoela (nemerteans) in western parts, molluscs (unidentified) in the eastern parts while the bivalve *Yoldiella* in the northern parts of the Barents Sea.

In the future, the bottom fauna will be quantitatively mapped in the feeding areas of cod and haddock, and the stomach content correlated to this bottom fauna, this might tell us if the fish are specialist (carefully select specific prey animals) or generalist (eat whatsoever available), how it feeds and where it feeds. This will supply to a better understanding of the marine benthic ecosystem.

Deep sea shrimp (*Pandalus borealis)* is an important prey for several fish species, especially cod, but also other fish stocks like blue whiting (ICES, 2007). Consumption by cod significantly influences shrimp population dynamics. The estimated amount of shrimp consumed by cod is on average much higher than shrimp landings.

2.5.4 Predation by fish

Cod diet

The diet of cod is a good indicator of the state of the Barents Sea ecosystem. Figure 2.37 shows the diet of cod in the period 1984-2006, calculated from data on stomach content, gastric evacuation rate and number of cod by age. The data for cod stomach content are taken from the Joint IMR-PINRO stomach content database (Mehl and Yaragina, 1992). The model for gastric evacuation rate for cod is based on experiments conducted at Norges Fiskerihøgskole in Tromsø. The consumption calculations show that the total consumption by cod in the last years has been around 4 million tonnes. The consumption per cod for the various age groups has also been fairly stable. Capelin was also in 2006 the most important prey item for cod, followed by krill, haddock, shrimp, herring, hyperiid amphipods, blue whiting, polar cod and cod. The proportion of capelin in the diet of cod decreased from about 50% in 1999-2003 to about 30% in 2004-2006, but is higher than the present low abundance estimate of capelin should indicate. This phenomenon was, however, also observed during the previous capelin collapse. Cod cannibalism is now at a low level, while the consumption of haddock by cod is at a record high level. There is a good correlation between prey availability and prey selection (i. e. stomach content) in cod. This can be seen both from the geographical and inter-annual variation in cod diet. The mature cod migrates out of the Barents Sea and spawns in the Lofoten area in March-April. The consumption rate by mature cod during this period is lower than during the rest of the year, with the main prey items being adult herring and Norway pout.

The individual growth of cod is close to average. The average age at first maturation has been declining the last decades, but now seems to have stabilized (ICES, 2007).

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 diet from crustaceans to fish is observed from age 1 to age 2. The diet of 2-year-old cod mainly comprised capelin (*Mallotus villosus)* and other fish, and to a lesser degree, krill and hyperiid amphipods. Shrimp (mainly *Pandalus borealis*) was also an important prey in both age 1 and 2 cod. For the period 1984-2002, a statistically significant positive relationship was obtained between capelin stock size and the amount of capelin in the diet of 2-year-old cod.

For cod age 3-6, the diet composition during the ecosystem survey 2006 was very variable between the areas, reflecting the difference in geographical distribution of the various prey items. In general shrimp, fish (mostly capelin, haddock, herring and polar cod) dominated in the cod diet. Fish including blue whiting was the dominant prey item in the south-western part, while shrimp, herring, krill, and capelin dominated in the south-eastern part. In the central Barents Sea shrimp and capelin were the most important prey in a large area, while polar cod dominated near Novaya Zemlya. In addition euphausiids and haddock prevailed in cod feeding in some areas.

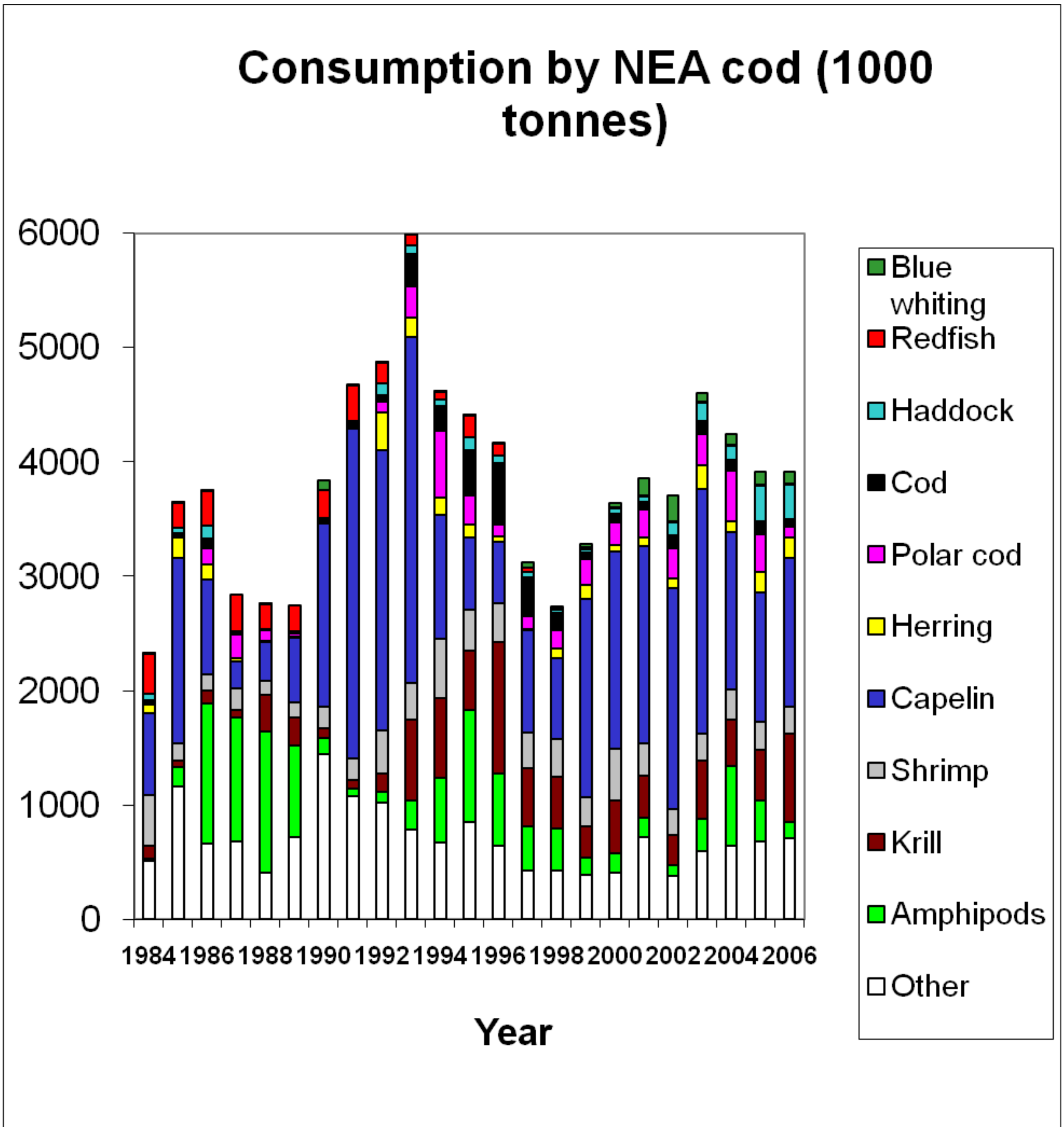


Figure 2.37. Consumption by Northeast Arctic cod in the period 1984-2006.

For cod age 7-12, the diet composition was to a large extent similar to that of age 3-6 cod, but weight percentages of euphausiids and shrimp were lower. Thus, fish including cod and haddock juveniles dominated in coastal areas near Russia. Polar cod, capelin and amphipods dominated north of 76° N, and polar cod dominated near Novaya Zemlya (the area east of 42° E and between 73° and 75° N). Shrimp was the dominant prey item in the central Barents Sea, but over a smaller area than for age 3-6 cod. In addition blue whiting was found in the western areas.

Blue whiting

Zooplankton is the most important prey at young ages of blue whiting (age < 5), which is the dominant part of the stock present in the Barents Sea (Anon., 2004). Among fishes, polar cod, capelin, haddock, saithe and redfish are the most important. The analysis of diet dynamics in blue whiting from different length groups showed a clear downward trend in the proportion of zooplankton by weight (copepods, hyperiids and euphausiids) and an increasing importance of fish. It should be noted that fish became the dominant part of blue whiting diet when it reached a length of about 27 cm. Cod juveniles occurred in the stomachs of blue whiting with a length of approximately 25 cm.

Clear differences in food composition of blue whiting in the different areas were reported by Belikov *et al.* (2004). The zooplankton (copepods and euphausiids) dominated in the feeding in the southern and central Barents Sea, while fish and large crustacea (hyperiids and shrimps) prevailed in the northern areas.

When present in the western Barents Sea the blue whiting is not the main prey for any other fish species. In these periods the blue whiting can be preyed upon at a rather low extent by cod and Greenland halibut. Due to the high numbers of cod, this is then the main fish predator on blue whiting. Other fishes, like larger saithe and haddock, may also prey on blue whiting, but the proportion of the diet is normally low. Information on predation of mammals on blue whiting in the Barents Sea is at present lacking.

How could this affect the rest of the ecosystem? It is reasonable to look for the answer both in the feeding habits of blue whiting, and in the knowledge about which predators feed on blue whiting. An increased amount of blue whiting in the Barents Sea may imply competition with other capelin predators, especially cod. Blue whiting will probably not have a significant impact on the recruitment of cod and other commercial fishes (haddock and redfishes). Increased competition between blue whiting and juvenile commercial fishes grazing on zooplankton is also possible.

Other species

The smaller individuals of saithe feed on crustaceans (mainly copepods and euphausiids), while larger saithe depends more on fish (Mironova, 1956; Lukmanov *et al*., 1975). Gastropods and cephalopods are also found in saithe stomachs. The main fish prey is young herring, Norway pout, haddock, blue whiting and capelin, while the dominating crustacean prey is krill. The importance of fish is highest in north, while in south the importance of crustaceans increases.

Long rough dab is a typical ichthyobenthophage, which main food is benthos (ophiurids, polychaets etc.) and different fish species. At older stages the proportion of fish increases (polar cod and cod, capelin and juvenile redfish). The larger long rough dab also feed on on their own juveniles and juvenile haddock, as well as on fisheries wastes.

The feeding habits of skates of the Barents Sea are rather different (Dolgov, 2005). Thorny skate preys primarily on fish and large crustaceans, shrimps and crabs, but may also in a lesser extent feed on fish. The most common fish species are young cod and capelin. In addition, fishery waste is a consideral part of the stomach content. Round skate fed mainly on bottom benthos, especially Polychaeta and Gammaridae. Northern shrimp and fisheries waste are also major components of their diets. Fish (mostly capelin and young cod) occurred in small quantities. Arctic skate feed mainly on fish (herring, capelin, redfish) and shrimp. Blue skate diet consists largely of fish, mainly young cod and haddock, redfish, and long rough dab). Spinytail skate also prey mostly on fish, which included haddock, redfish and long rough dab.

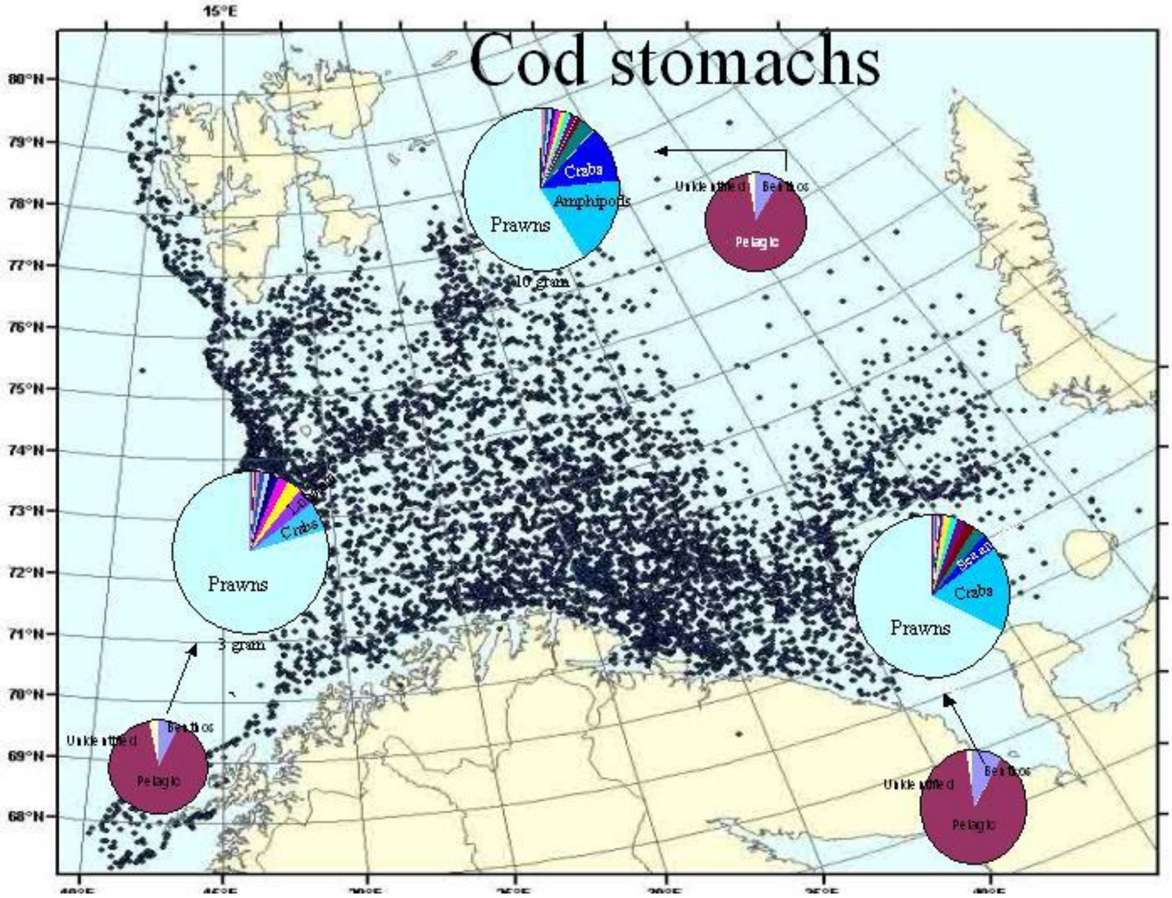


Figure 2.38. The stomach content (small reddish circles) of cod (7-11 years old) and detailed information (large bluish circles) on what animal groups (less that 10 % of total stomach content) that constitute bottom species.

2.5.5 Predation by mammals

To investigate marine mammal - prey interactions, and hence the role of marine mammals in the Barents Sea ecosystem, stomach content of minke whales and harp seals have been sampled and analysed for several years (Haug *et al.*, 1995; Nilssen *et al.*, 2000). A sampling program on harp seal diet is still ongoing at IMR. Furthermore, in July from 2000 to 2002, marine mammal observers took part in annual IMR cruises along the Barents Sea shelf edge, and marine mammal observers have also participated on the ecosystem surveys in the Barents Sea Agust – September since 2003. As predators tend to aggregate where their prey is abundant (e.g. Fauchald and Erikstad, 2002, Mauritzen *et al.* in press), we can identify marine mammal – prey interactions as consistent positive spatial associations between marine mammals and their preferred prey species.

Consumption estimates by minke whale (Folkow *et al.* 2000) and harp seal (Nilssen *et al.*, 2000) are given in Table 2.1. 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). The consumption by harp seal is calculated both for situations with high and low capelin stock, while the consumption by minke whale is calculated for a situation with a high herring stock and a low capelin stock. Food consumption by harp seals and minke whales combined is at about the same level as the food consumption by cod, and the predation by these two species needs to be considered when calculating the mortality of capelin and young herring in the Barents Sea. However, as can be seen from the harp seal consumption estimates, the dietary importance of the different prey species depends highly on the prey species' availability. 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). The major part of the consumed herring belonged to the strong 1991 and 1992 year classes and 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 in turn likely reduced the role of herring as prey in the Barents Sea, which is reflected by a more northern minke whale distribution in 1995 compared to earlier years (Eriksen et al. submitted). At the other hand, the importance of herring as prey likely 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 et al. submitted).. 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 decrease below a certain level (Lindstrøm *et al.* 2002).

To understand the dynamics of the upper trophic levels in the Barents Sea, it is also important to understand how interactions between marine mammals and prey change throughout the year. Therefore, harp seal diet data was collected in spring and early summer over three years (2004-2006) in southwestern, central and northwestern Barents Sea. The data obtained supplement similar data obtained in open waters east of Svalbard in July and August in 1996 and 1997. The results indicate a harp seal summer diet comprising almost exclusively krill and polar cod, while other gadoids and capelin seems to be of very little importance (Figure 2.39, Lindstrøm et al. 2006). This is in good agreement with suggestions made by Nilssen et al. (2000) that krill is an important food source for harp seals during the summer period (May-August). Krill occurred in significantly higher amounts in the seal stomachs than any other prey species except for July when polar cod dominated. However, in both study periods (1996/1997 and 2004/2005) the capelin stock was at a very low level. This may certainly have influenced the observed seal diets – so far no summer samples are available in periods with good capelin abundance in the Barents Sea.

Investigations of spatial associations between marine mammals and prey along the Barents Sea shelf edge (2000-2002) and in the Barents Sea (2003-2006) show that marine mammal – prey interactions vary geographically. Along the shelf edge, minke and fin whales and *Lagenorhynchus* dolphins were significantly associated with capelin, and in addition minke whales were associated with herring and fin whales with zooplankton (Mauritzen *et al*., in press). However, our analyses suggest that prey selection of these species are habitat specific. For instance, while minke whales where associated with capelin in warmer Atlantic water masses, fin whales associated with capelin along the polar front and *Lagenorhynchus* dolphins in colder waters mainly on the shelf (Mauritzen et al. *in press*). Such habitat-specific prey selection may relieve interspecific competition for the most dominating and important prey species in the Barents Sea.

Table 2.1. 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 Parathemisto

Information collected on spatial associations of marine mammals and prey in the Barents Sea 2003-2006 will be analyzed in detail in 2007, but some preliminary results are available. Figure 2.40 show the distribution of the four pelagic fish species polar cod, capelin, herring and blue whiting, as observed acoustically along the survey transects in 2003-2006, relative to the most frequently observed cetacean species; *Lagenorhynchus* dolphins (whitesided and whitebeaked dolphins), minke whales and humpback whales. While *Lagenorhynchus* dolphins and common minke whale occurred throughout the Barents Sea and along the Barents Sea shelf edge, humpback whales were predominantly observed along the shelf edge and in the deeper troughs around Bear and Hopen Islands. *Lagenorhynchus* dolphins mainly overlapped with capelin in central and northern Barents Sea, and blue whiting and herring in southern and western Barents Sea. Common minke whale overlapped consistently with herring in southern Barents Sea and with capelin in central, northern and eastern Barents Sea. Overlap with blue whiting only occurred when also herring was present, suggesting that herring was the preferred prey species in this region. Humpback whales, often occurring in associations with both minke whales and *Lagenorhynchus* dolphins, overlapped consistently with capelin in central Barents Sea, but few occurrences of overlap between humpback whales and pelagic fish along the shelf edge and around Bear Island suggest other prey species than pelagic fish, such as krill, to be important in this area. Hence, our preliminary results suggest that capelin and herring are important prey species for these cetaceans during fall, and that blue whiting, currently increasing in abundance in the Barents Sea, may be an important prey species for *Lagenorhynchus* dolphins, but not for the baleen whales. Of course, in depth analyses of spatial concordance is needed to verify these preliminary conclusions. Furthermore, more information on krill distribution is needed for thorough understanding the marine mammal-prey interactions in the Barents Sea.

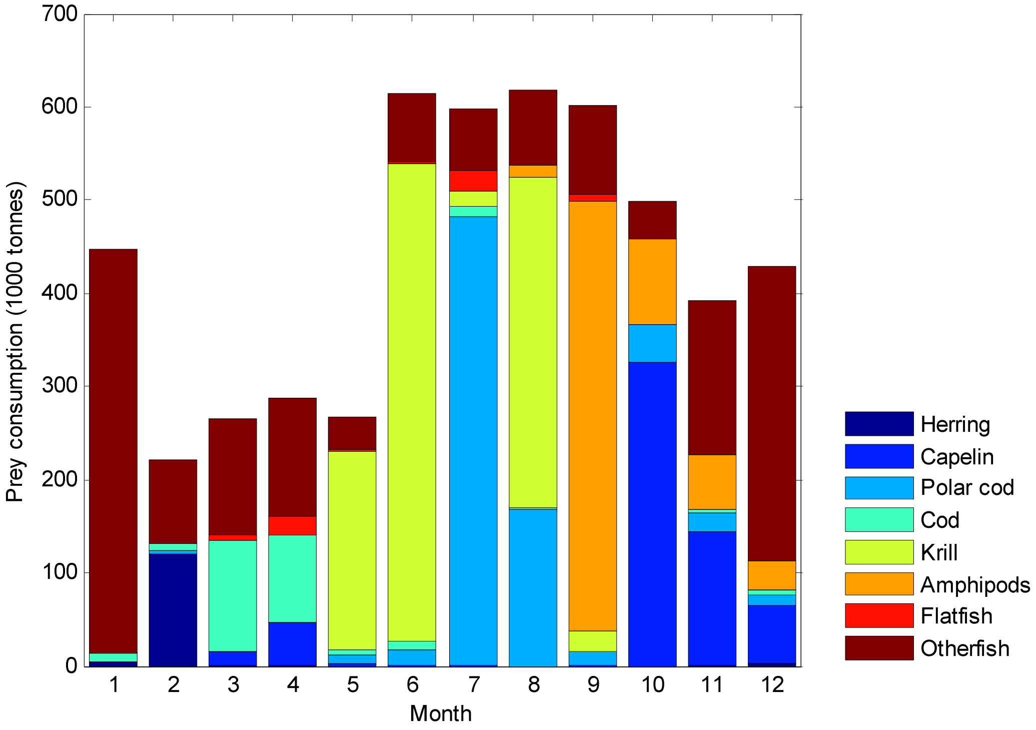


Figure 2.39. Monthly variation in harp seal consumption through the year.

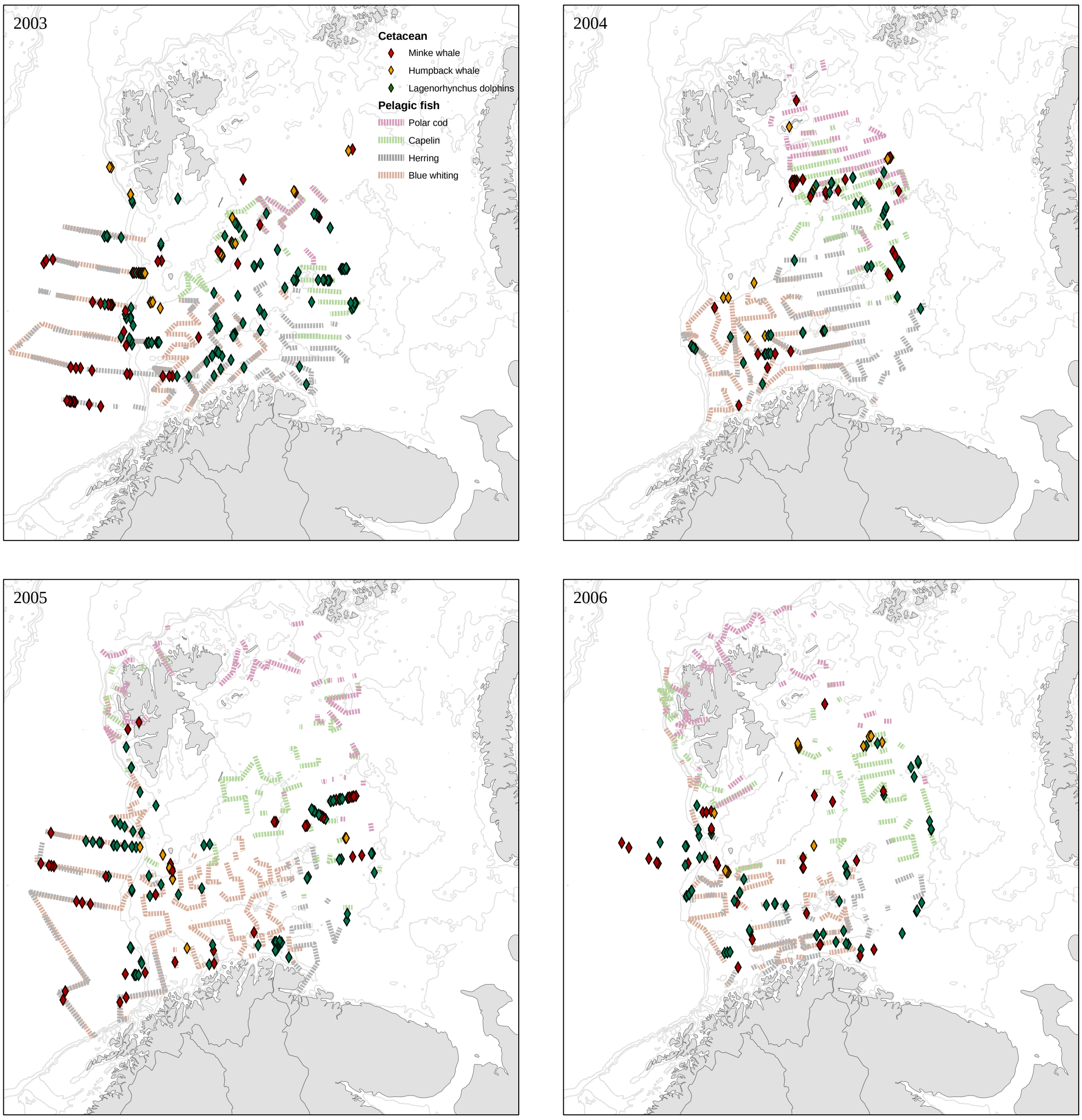


Figure 2.40. Observations of minke and humpback whales and Lagenorhynchus dolphins (diamonds) relative to distribution of polar cod, capelin, herring and blue whiting (scattered lines) as observed during parts of the ecosystem surveys in August-October 2003-2006. Colour codes are given in legend in upper left figure.

3 Impacts of the fisheries on the ecosystem

By S. Aanes, K. V. Drevetnyak, A. A. Grekov, K. Nedreaas and K. M. Sokolov

3.1 General description of the fisheries and mixed 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, with ling and tusk also found at the slope and in deeper waters. In 2006, catches slightly less than 1.0 million tonnes are reported from the stocks of cod, haddock, saithe, redfish, Greenland halibut and shrimp, not including unreported landings of cod and haddock. This is an increase of about 10% compared to 2005. An additional catch of about 100 000 tonnes was taken from other demersal stocks, including crustaceans, not assessed at present. 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 shows 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 3.1). The major pelagic stocks are capelin, herring, and polar cod. There was no fishery for capelin in the area in 2004, 2005 and 2006 due to a stock in poor condition, and there is no directed fishery for herring in the area. The exploitation of polar cod has been very small since the 1970s. The highly migratory species blue whiting and mackerel extend their feeding migrations into this region, but there is no directed fishery for the species in the area. Species with relatively small landings include halibut, Norway pout, anglerfish, lumpsucker, argentines, grenadiers, flatfishes, dogfishes, skates, king crab, other crustaceans, echinoderms, sponges and molluscs.

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

For some of the exploited stocks (*e.g.* cod, haddock, capelin, harp seal, minke whale, king crab) an agreed quota is decided (TAC). In addition to an agreed quota, a number of regulations are applied. The regulation differs among gears and species and may be different from country to country, and a non-exhaustive list is summarised in Table 3.1 along with a description of the fisheries.

Table 3.1. 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), minimum landing size (MLS), 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), restriction in effort combined with quota and tonnage of the vessel (ER).

Species	Directed fishery by gear	Type of fishery	Reported Landings in 2006 (tonnes)	As by-catch in fleet(s)	Location	Agreements and regulations
Capelin	PS, TP	seasonal	0	TR, TS	Northern coastal areas to south of 74°N	bilateral agreement, Norway and Russia
Coastal cod	GN, LL, HL, DS	all year	26134[1]	TS, PS, DS, TP	Norwegian coast line	Q, MS, MCS, MBU, MBN, C, RS, RA
Cod	TR, GN, LL, HL	all year	469197[2]	TS, PS, TP, DS	North of 62°N, Barents Sea, Spitsbergen	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Wolffish[3]	LL	all year	21081[5]	TR, (GN), (HL)	North of 62°N, Barents Sea, Spitsbergen	Q, MB
Haddock	TR, GN, LL, HL	all year	131857[2]	TS, PS, TP, DS	North of 62°N, Barents Sea, Spitsbergen	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Saithe	PS, TR, GN	seasonal	212480	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[5]	LL, GN	Seasonal	17910	TR	deep shelf and at the continental slope	Q, MS, RS, RG, MBH, MBL
Sebastes mentella	No directed fishery	all year	31457	TR	deep shelf and at the continental slope	C, SG, MB
Sebastes marinus	GN, LL,HL	all year	7690	TR	Norwegian coast	SG, MB MCS, MBU, C
Shrimp	TS	all year	40778[6]		Spitsbergen, Barents Sea, Coastal	ED, EF, SG, C, MCS

[1] Estimated total catch

[2] There are two different estimates of unreported catch; 127000 and 28000 tonnes for cod, and 40316 and 8889 tonnes for haddock not included in this figure.

[3] The directed fishery for wolffish is mainly Russian EEZ and in ICES area IIB, and the regulations are mainly restricted to this fishery

[4] Total catch in 2004

[5] The only directed fishery for Greenland halibut is by a limited Norwegian fleet, comprising vessels less than 28 m.

[6] Total catch in 2005

Estimates of unreported catches of cod and haddock in 2002 - 2006 indicate that this is a considerable problem. Unreported landings are estimated with two different approaches, but the method and estimates used by ICES amounts to 90 000-166 000 tonnes cod annually during this time period, or 20-35% of the official landings (ICES 2007/ACFM:16). Similar estimates for cod and haddock amount the annual unreported landings to 19 000-40 000 tonnes or 19-34% of the official landings. Unreported landings will reduce the effect of management measures and will undermine the intended objectives of the harvest control rule. Discarding of cod, haddock and saithe is believed to be significant in periods although discarding of these, and a number of other species, is illegal in Norway and Russia. Data on discarding are scarce, but attempts to obtain a better quantification of this matter continue.

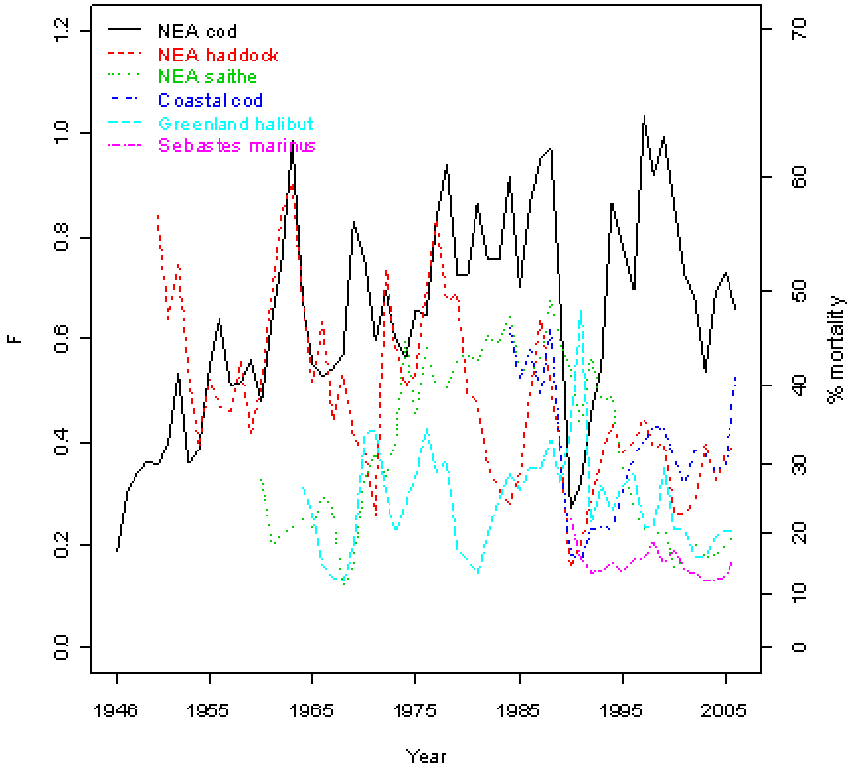


Figure 3.1. Time series of annual average fishing mortalities for Northeast Arctic cod (time period 1946-2006, average for ages 5-10), Northeast Arctic haddock (time period 1950-2006, average for ages 4-7), Northeast Arctic saithe (time period 1960-2006, average for ages 4-7), coastal cod (1984-2006, average for ages 4-7) and Greenland halibut (time period 1964-2006, average for ages 6-10) and Sebastes marinus (time period 1987-2006, average for ages 12-19).

3.2 Mixed fisheries

The demersal fisheries are highly mixed, usually with a clear target species dominating, and with low linkage to the pelagic fisheries (Table 3.2). Although the degree of mixing may be high, the effect of the fisheries will vary 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 on having 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 is largely missing due to a need for improving methodology combined with lack of necessary data. However, technical interaction between the fisheries can be explored by the correlation in fishing mortalities among species. The correlation in fishing mortality is positive for Northeast Arctic cod and coastal cod (p=0.001), haddock and coastal cod (p=0.01) and Northeast Arctic cod and saithe (p=0.391) confirming the linkage in these fisheries (Figure 3.2). There is also a significant relationship between Saithe and Greenland halibut (p=0.017) although the linkage in these fisheries is believed to be small (Figure 3.2). 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, but is considered too simple since this correlation is influenced by too many confounding factors whose effect cannot be removed without a detailed analyses on a higher resolution of the data (e.g. saithe and Greenland halibut, Figure 3.2) and on e.g. changes in distribution of the stocks (ICES 2006/ACFM:14).

A further quantification of the degree of mixing and impact among species 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. In 2006 the composition of cod, haddock, saithe, Greenland halibut, Sebastes marinus, Sebastes mentella and other species caught by the Russian and Norwegian trawl fleet shows large spatial differences in both catch compositions and catch sizes as well as large differences between the countries (Figure 3.3-Figure 3.6). Overall the proportion of cod in the Russian trawl fishery is higher than in the Norwegian trawl fishery. In the north eastern part of the Barents Sea the major part of the catches consists of cod in the Russian fishery, while the Norwegian includes a large proportion of other species (shrimp). In the western part of the Barents Sea the Norwegian catches consists of Sebastes mentella and Greenland halibut while the Russian catches mainly consist of cod. The main reason for this difference is the difference in spatial resolution of the data; the strata for the Norwegian system extend more westerly and cover the fishing grounds for Greenland halibut, while the Russian strata do not. The Norwegian trawl fishery along the Norwegian coast includes areas closer to the coast and is also more southerly distributed where other species to a higher degree dominates the catches (e.g. saithe). The available data for other years and with higher resolution has not yet been gathered and compiled for a further quantitative analysis, which is necessary to obtain information of the actual mixing in the various fisheries to approach consistent advices across all stocks.

Table 3.2. Flexibility in coupling between the fisheries. Fleets and impact on the other species (H, high, M, medium, L, low and 0, nothing). The lower diagonal indicates what gears couples the species, and the strength of the coupling is given in the upper diagonal. 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).

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	

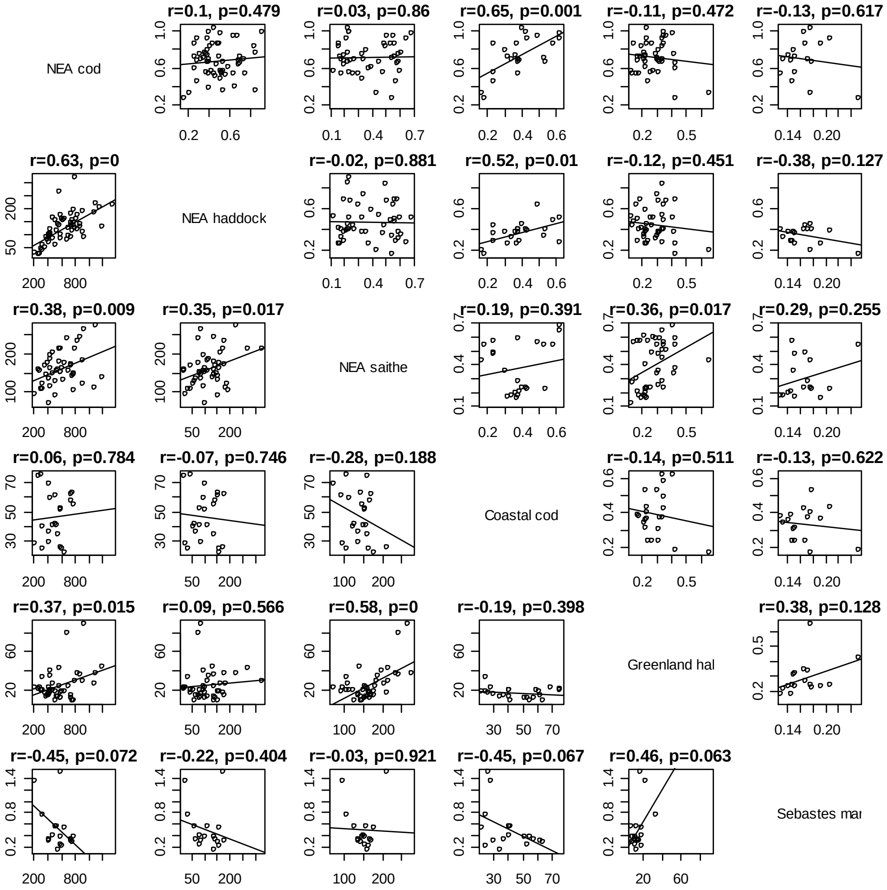


Figure 3.2. Pairwise plots of annual average fishing mortalities (upper diagonal) and landings (1000 tonnes) (lower diagonal) for overlapping time periods for Northeast Arctic cod (time period 1946-2006, average for ages 5-10), Northeast Arctic haddock (time period 1950-2006, average for ages 4-7), Northeast Arctic saithe (time period 1960-2006, average for ages 4-7), coastal cod (1984-2006, average for ages 4-7), Greenland halibut (time period 1964-2006, average for ages 6-10) and Sebastes marinus (time period 1987-2006, average for ages 12-19). The correlation and the corresponding p-value are given in the legend.

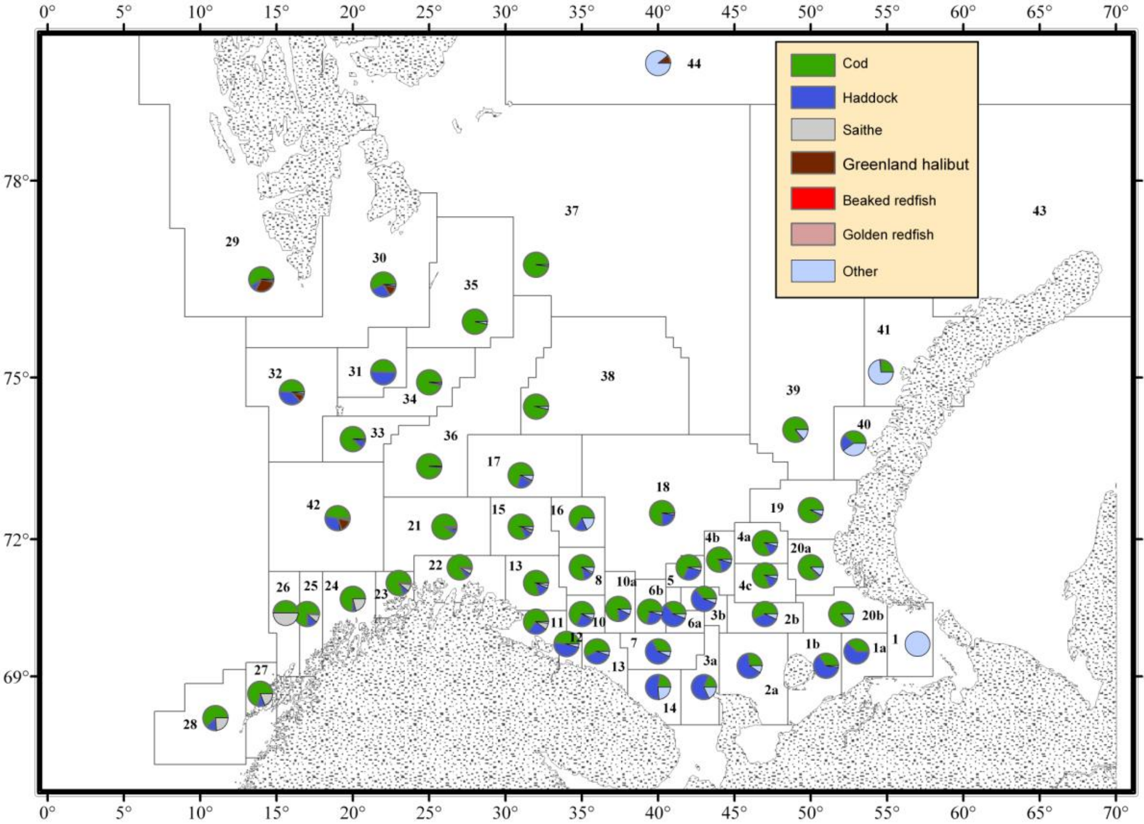


Figure 3.3. Relative distribution of composition of cod, haddock and other species taken by Russian bottom trawl in 2006 per main areas for the Russian strata system by weight.

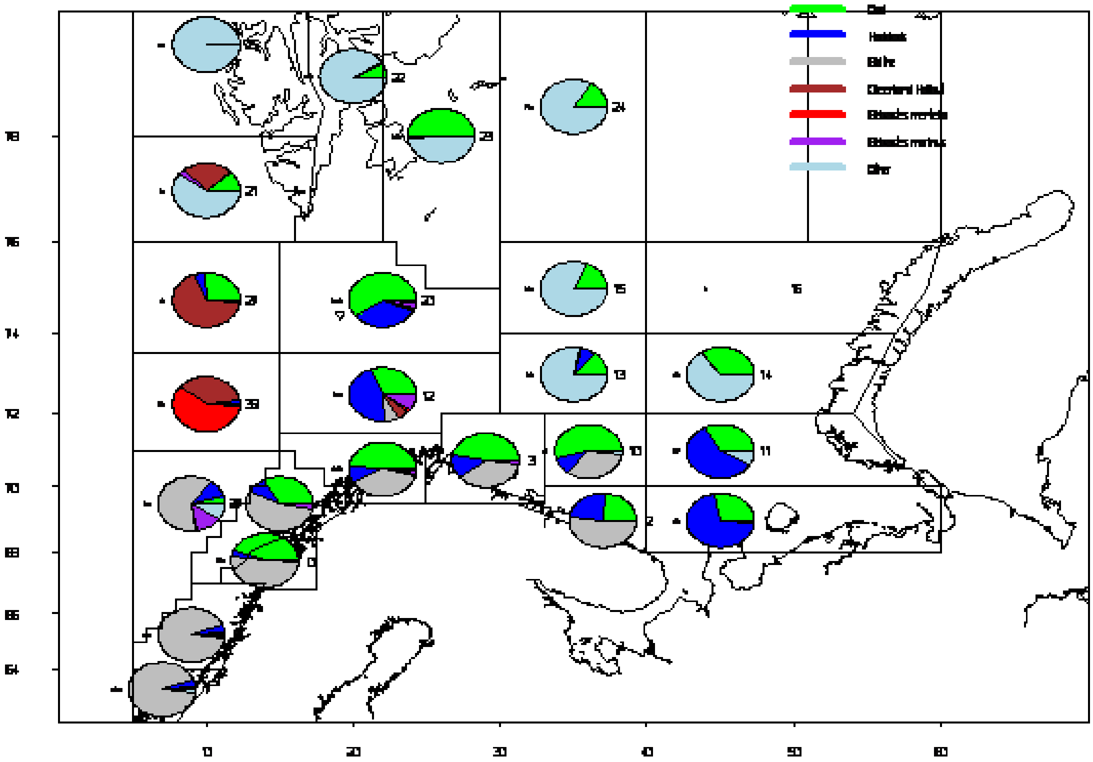


Figure 3.4. Relative distribution of composition of cod, haddock and other species taken by Norwegian bottom trawl in 2006 per main areas for the Norwegian strata system. The large numbers to the right of the pie diagrams are the name of the stratum, while the small numbers to the left is the number of vessel days recorded in the area.

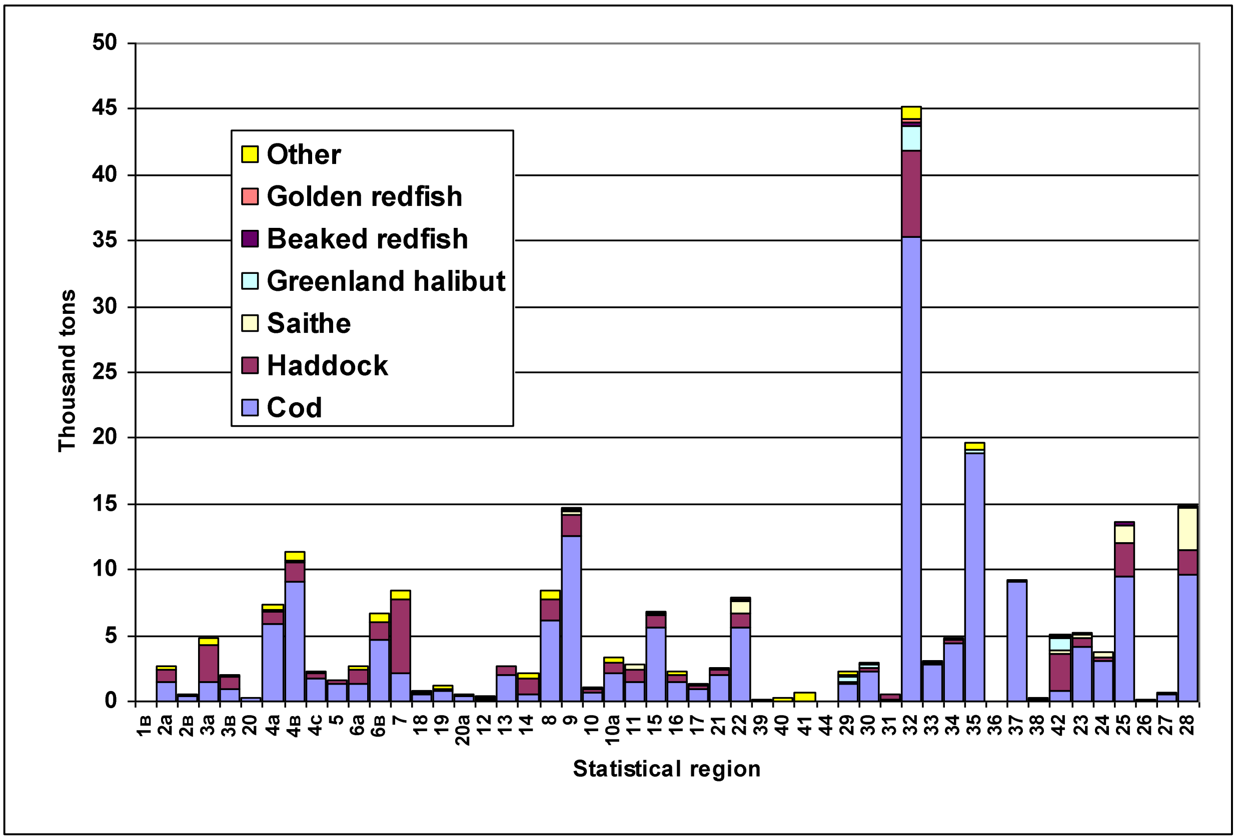


Figure 3.5. The Russian catch of cod, haddock and other species taken by bottom trawl by main statistical areas in 2006, thousand tons. The statistical areas correspond to the areas shown in Figure 3.3.

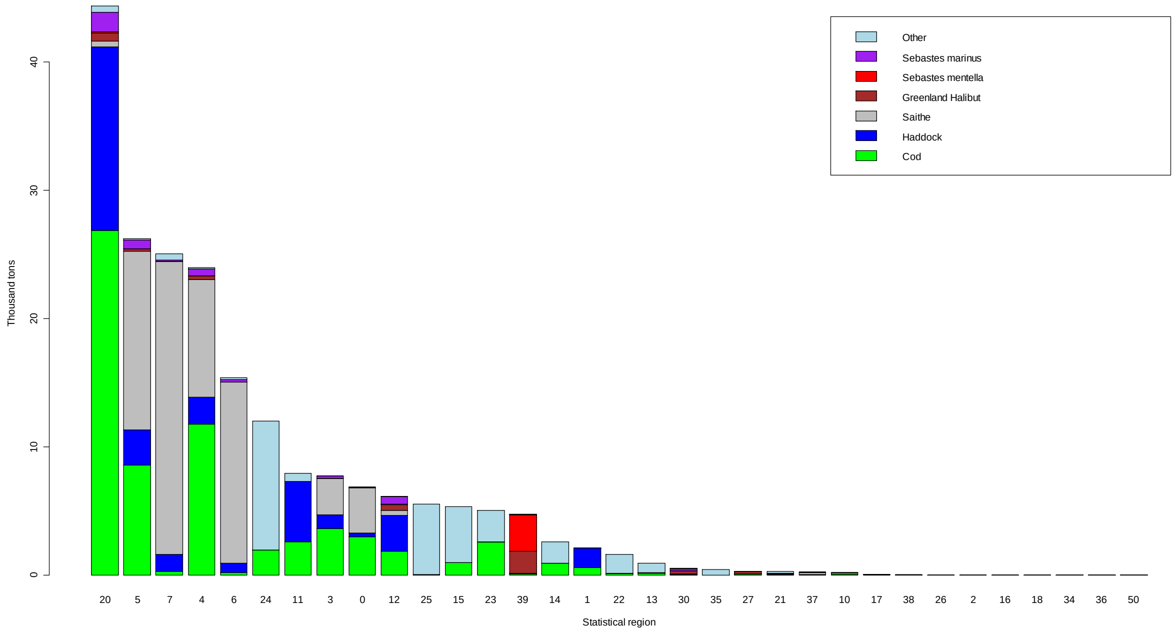


Figure 3.6. The Norwegian catch of cod, haddock and other species taken by bottom trawl by main statistical areas in 2006, thousand tons. The statistical areas correspond to the areas shown in Figure 3.4.

3.3 Impact and by-catches of non-target species

Though one of the most important factors determining the magnitude and direction of long-term changes is likely to be fishing intensity (e.g. Poiner et al. 2000, cited in Pitcher et al. 2000), data on effects from bottom trawling on Barents Sea benthic communities are sparse. Based on today's knowledge, the absence of large attached epifauna on hard-bottom substratum may be the only benthic sign of intensive bottom trawling. In general, the response of benthic organisms to disturbance differs with substrate, depth, gear, and type of organism (Collie et al. 2000). 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. In sandy bottoms of high seas fishing grounds trawling disturbances have not produced large changes in the benthic assemblages, as these habitats may be resistant to trawling due to natural disturbances and large natural variability. 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.

Natural disturbance is high in shallow water (strong tidal currents) around Bear Island and supposed to modify the benthic fauna (Gulliksen 1979). Long-term effects have not been documented during an 18-month trawl impact study off Bear Island (Humborstad 2004).
Very deep, stable environments are probably most vulnerable, but to our knowledge no studies have been conducted below 200 m to date. However, shifts from dominance by high biomass organisms towards communities dominated by small-bodied opportunistic species have been observed in areas that have been affected by trawling over longer time periods (Ball et al. 2000; McConnaughey et al. 2000; Kaiser et al. 2002).

Barents Sea hard bottom substrata, with associated attached large epifauna should therefore be identified. 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; Kaiser et al. 2002). The recovery time of the benthic community should be investigated. But for many species there is a lack of life-history data that would enable us to draw firm inferences about relative vulnerability (Hall 1999). Only by combining such data with microscale data on the distribution and frequency of trawling disturbance of major fishing grounds we can accurately assess the extent of impact on benthic habitats (Kaiser et al. 2002). Some maps on fishing effort do exist (e.g. Figure 5.23) but their resolution and detail are too large in scale to draw inferences about fishing impacts (Humborstad 2004). 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).

Lost gears, such as gillnets, may continue to fish for a long time (ghostfishing). The catching efficiency of lost gillnets has been examined for some species and areas (*e.g.* Humborstad *et al.,* 2003), 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. 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, in prep). In 2004 Norway initiated a monitoring program on by-catches of marine mammals in fisheries (Bjørge *et al.,* 2006). 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, and where bird by-catch is a problem, the bird scaring line is used without any forced regulation.

4 Monitoring of the ecosystem

By J. E. Stiansen and A. A. Filin

Monitoring of the Barents Sea started already in 1900 (initiated by Nikolay Knipovich), with regular measurement of temperature in the Kola section. In the last 50 years monitoring of ecosystem components in the Barents Sea on a regular basis have been conducted by PINRO and IMR at several standard sections and fixed stations as well as by area covering surveys. 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.

4.1 Standard sections

Some of the longest ocean time series in the world are along standard sections (Figure 4.1) in the Barents Sea. The monitoring of basic oceanographic variables for most of the sections goes back 30-50 years, with the longest time series stretching over one century. In the last decades also zooplankton is 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 4.1. Specific considerations for the most important sections are given in the following text.

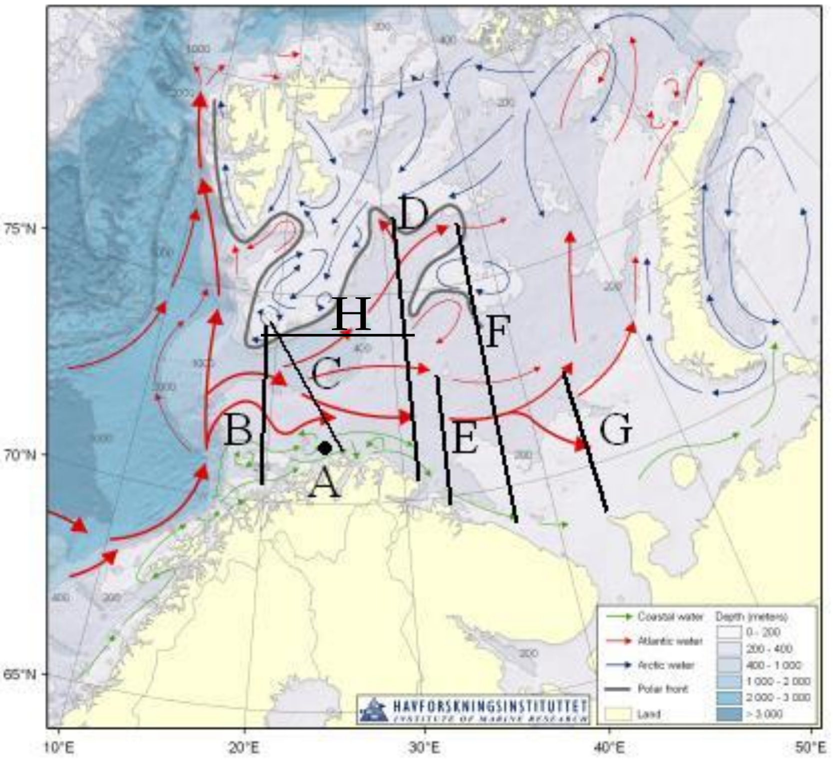


Figure 4.1. Positions of the standard sections monitored in the Barents Sea. A is fixed station Ingøy, B is Fugløya-BearIsland, C is North cape-Bear Island, D is Vardø-North, E is Kola, F is Sem Island-North G is Kanin section and H is Bear Island-East section.

Table 4.1. 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 pr year	T,S,N,chla,zoo
North cape-Bear Island	PINRO	1929-present	1-26 times pr year	T,S
Bear Island-East	PINRO	1936-present	1-15 times pr year	T,S
Vardø-North	IMR	1977-present	4 times pr year	T,S,N,chla
Kola	PINRO	1900-present	2-30 times pr year	T,S,O,N, zoo
Kanin	PINRO	1936-present	1-11 times pr year	T,S
Sem Islands	IMR	1977-present	Intermittently*	T,S

* The Sem Island section is not observed each year

4.1.1 Fugløya-Bear Island section

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 in August since 1964, and the observation frequency increased to 6 times per year in 1977. Zooplankton monitoring began in 1987.

4.1.2 North cape-Bear Island section

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 is observed on a quarterly basis.

4.1.3 Bear Island – East section

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.

4.1.4 Vardø-North section

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 usually is in Arctic water masses.

4.1.5 Kola section

The Kola section is situated partly in the coastal water masses and partly in the Atlantic water masse, and is the section most representative for the Atlantic branch going eastwards parallel to the coastline, i.e. the southern part of the Barents Sea. Some gaps in the time series exists, 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.

4.1.6 Kanin section

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.

4.1.7 Sem Island

Observations on the Sem Island section has been conducted intermittently since 1977. In the period 1997-1995 the section was observed regularly 2 times a year. Later it has been observed only a few times, with the latest observation in 2000.

4.2 Fixed stations

IMR operates one fixed station, Ingøy, 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.

4.3 Area coverage

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. Effort is always put on measuring as many quatities as possible on each survey, but available time put restrictions on what is possible to accomplish. 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 quatities/species. Other measured quatities may therefore not have optimal coverage and thereby increased uncertainty, but will still give important information. An overview of the measured quatities/species on each main survey is given in Table 4.2. Specific considerations for the most important surveys are given in the following text.

Table 4.2. 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**	**Phyto-plankton**	**Zoo-plankton**	**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 surveys	**IMR**	**Oct-Nov**	**T,S**	**N,chla**	**Yes**	**Herring, sprat, demersial species**	**Saithe, coastal cod**	**-**	**-**
Autumn-winter trawl-acoustic survey	**PINRO**	**Oct-Des**	**T,S**	**-**	**Yes**	**Demersial species**	**Demersial species**	**-**	**-**
Survey on estimation of abundance of young herring	**PINRO**	**May**	**T,S**	**-**	**Yes**	**Pelagical species**	**Herring**	**-**	**-**
Norwegian Greenland halibut survey	**IMR**	**Aug**	**-**	**-**	**-**	**-**	**Greenland halibut, redfish**	**-**	**-**

4.3.1 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.

4.3.2 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. Trawl samples are not taken according to a proper trawl survey design. This is due to practical reasons. The spawning concentrations can be located with echosounder thus 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.

4.3.3 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. 2-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.

4.3.4 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 Spitsbergen. 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. 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).

4.3.5 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.

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

This survey is conducted in May and takes 2-3 weeks. It is including also observations of physical oceanography and plankton. In 1991-1995 it was joint survey, since1996 the survey is carrying out by PINRO.

4.3.7 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.

4.4 Numerical models

Large 3D hydrodynamical numeric models for the Barents Sea are run at both IMR and PINRO. These models 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.

Sub-models for phytoplankton and zooplankton 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.

4.5 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.
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.
Along the Norwegian coast ship-of-opportunity supply weekly the surface temperature along their path.

4.6 Monitoring divided by ecosystem components

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.

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. Data from 2005 and 2006 include analysis on species composition from water samples, covering the same area as for zooplankton. In addition to observations, the primary production is simulated using numerical models.

Zooplankton monitoring

Zooplankton area coverage is monitored during the joint autumn ecosystem survey. Joint investigations have taken place since 2002. Regular sampling by IMR began in 1979. A Juday net is used to obtain zooplankton samples by PINRO, where as IMR use WP2 as a standard zooplankton gear. In 2005 comparisons were made between the Juday (37 cm in diameter, 180µm) and WP2 (56 cm in diameter, 180µm) net catches from the joint autumn cruises both with regard to biomass and species composition. The biomass values obtained by the two gears yielded quite similar results. A report on these 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.

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. However, the 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 some vertically stratified MOCNESS stations are also taken each year.

Regular macroplankton area 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. In the survey the trawl net was attached to the upper headline of the bottom trawl. 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 can be 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 the euphausiids are determined.

Benthos monitoring

Monitoring of the shrimps and the benthos community takes place during the joint autumn ecosystem survey. To cover a need of basic mapping of the bottom animals in the Barents Sea the project MAREANO started its activity in summer 2006. Within the next years the southern ice-free areas of the Barents Sea will be mapped. 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. 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.

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 fishing vessels.

Mammals monitoring

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. Since 2002 distribution of marine mammals in the Barents Sea are observed from research vessels during the ecosystem survey. In addition aircraft observations and observations from fishing vessels with observers are used. In the White Sea aircraft observations are used to estimate the abundance of harp seals.

Birds monitoring

The distributions of birds in the Barents Sea are observed from research vessels during the ecosystem survey. In addition aircraft observations and observations from fishing vessels with observers are used.

5 Current and expected situation of the ecosystem

5.1 Overview

By Å. Høines, A. Filin, E. Johannesen and J.E. Stiansen

5.1.1 Climate

The temperature in the Barents Sea has been above normal in recent years, and is currently close to an all-time high for the period where observations are available. The south western area showed record temperatures in 2006. Although the changes are not very large, they may still cause changes in the ecosystem. The temperature conditions in the Barents Sea are, for some of the species found there, probably close to the limit of what they can adapt to. Then even a minor temperature change may lead to an increase of the distribution area. Changes in distribution of species might also cause changes in species overlap and hence predator-prey relations. Temperature itself is not the only relevant factor in this context. An increase in temperature may either be due to an increased inflow of Atlantic water, or to a higher temperature of the water flowing into the Barents Sea. During the winter of 2006 the volume flux of Atlantic Water was the highest recorded since the observations started in 1997. Increased inflow will lead to increased abundance of nutrients and planktonic organisms, and this may lead to changes in living conditions for the fish species in the Barents Sea and enhance growth and survival. The ice cover was in general much lower than average in 2006 and the winter ice cover has not been seen as low since 1970.

5.1.2 Phytoplankton and Zooplankton

The spring bloom of phytoplankton in 2006 was relatively early. In addition to available nutrients the onset of the spring bloom depends heavily on factors such as stratification and light. Total zooplankton biomass was above average, but with similar spatial variations as in 2005.

5.1.3 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 trawling 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 and in the Hopen Deep.

The indices of stock size of Northern shrimp (*Pandalus borealis*) have increased since 2004. In 2006, the distribution of red king crab **(***Paralithodes camtschaticus***)** was characterized by dense concentrations in the eastern part of the Russian waters where the majority of the catches were taken. Management of the red king crab in the Barents Sea was a joint management between Russia and Norway until 2006 when the two parties decided to carry out separate management in the two different economical zones. Most part of the Iceland scallop (*Chlamys islandica*) fishable stock was found in the area of Svyatoy Nos Cape (Svyatoy Nos scallop settlement) where the basic fishery was concentrated. Since 2005 a tendency for a growth in the fishable stock has been observed.

5.1.4 Fish

The cod stock was estimated to remain at a relatively stable level in 2006 with a SSB somewhat above the precautionary approach level B_{pa} (i.e. having full reproductive capacity), but being exploited with an unsustainable fishing mortality (well above F_{pa}). The stock of haddock was estimated to be increasing and well above B_{pa} in 2006. However, the fishing mortality was somewhat above F_{pa}. There was a small increase in the survey indices of redfish in 2006 but they are all still at a historically very low level. The estimated stock size of Greenland halibut also remained stable in 2006. Among the pelagic species, the acoustic abundance estimate of capelin increased from 2005 to 2006, but d the probability of having a SSB below the limit value for catch recommendation (B_{lim}) in 2007 was estimated to be high. The estimated stock size of herring and blue whiting in the Barents Sea decreased somewhat from 2005 to 2006, but were still relatively high. The polar cod acoustic abundance index increased to an all-time high 2006.

5.1.5 Mammals and seabirds

Both high temperatures and low capelin abundance likely influenced marine mammal distributions in 2006 in the Barents Sea. The most abundant and widely distributed cetaceans were white-beaked dolphins, minke whales and humpback whales, while harbour porpoises were abundant along the coast. Although both the most abundant marine mammals were observed associated with capelin, their distributions also overlapped with herring and polar cod, and likely with krill. Fin whales and northern bottlenose whales were observed more frequently in central and eastern Barents Sea in 2006 than in previous years. The estimated number of harp seal pups on whelping grounds in the White Sea in 2006 indicates a continuing decrease in their pup production.

26 different species of seabirds were observed during the autumn ecosystem cruise in the Barents Sea. Northern fulmar was the single most observed species, but northern fulmar and gulls are typical ship-followers; they are therefore likely overrepresented relative to the other seabird species observed.

It is important to note that the observed distributions of marine mammals and seabirds are very dependent on weather conditions at the cruise and unfavourable weather and light conditions may yield biased distribution maps. As both marine mammals and seabirds common to the Barents Sea are long-lived species, their abundances are not likely to be heavily influenced by year-to-year fluctuations within the system.

5.2 Climate

By R. Ingvaldsen, P. Budgell, A. L. Karsakov, V. K. Ozhigin, A. P. Pedchenko,O. Titov and B. Ådlandsvik

5.2.1 Atmospheric conditions

5.2.1.1 Wind field

In winter 2005/2006, 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 5.1). 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 southerly winds prevailed over the southeastern part of the sea, while light easterlies dominated the northern Barents Sea. In summer 2006, horizontal air pressure contrasts were considerably smaller than in winter, and weak westerly winds prevailed over most of the Barents Sea (Figure 5.2). Stronger southwesterlies dominated the Barents Sea Opening and Bear Island – Spitsbergen area.

5.2.1.2 Air temperatures over the sea

Air temperature data were taken at http://nomad2.ncep.noaa.gov and averaged over western (70-76°N, 15-35°E) and eastern (69-77°N, 35-55°E) parts of the sea. In the early 2006, the air temperature over the Barents Sea was well above normal, with maximal values of positive anomalies (4.0-5.0 ºC) in the eastern sea (Figure 5.3). In summer and autumn temperature anomalies decreased. Insignificant positive anomalies of air temperature were registered in the western Barents Sea and, in the eastern part of the sea, negative anomalies (0.4-0.7 ºC) were observed in June-July and October. In November-December, over the most of sea, air temperature was, on average, 2.0-3.0 ºC higher than the long-term mean.

5.2.1.3 Air temperature at the weather stations

Table 5.1 summarizes air temperature anomalies at some meteorological stations at the western and southern Barents Sea during the period from late 2005 through 2006 and into early 2007. In winter 2005/2006 air temperature over the region was considerably warmer-than-normal (by 0.0-3.6 °C), with highest anomalies at the Bear Island (7.2 °C) and Spitsbergen airport (12.0 °C). March 2006 was colder-than-usual at all stations but Spitsbergen airport. April was warm again with mean temperature anomalies ranging from 2.1 °C at Tromsø to 10.7 °C at Spitsbergen airport. During May-October temperature anomalies were predominantly positive but considerably smaller than in winter. During late autumn and winter 2006/2007 (November-January) positive anomalies rose again compared to summer months. In the southern part of the sea (Tromsø, Vardø, Murmansk and Kanin Nos), air temperature was warmer-than-normal by 0.2-4.7 °C, highest anomalies were registered at Murmansk in November (11.5 °C) and December (12.0 °C). In the northwestern Barents Sea (Spitsbergen airport and Bear Island) positive anomalies ranged from 3.2 °C to 6.0 °C. Mean annual air temperature in 2006 was warmer-than-average by 0.5-4.3 °C. It was highest on record at stations Bear Island (1949-2006) and Spitsbergen airport (1977-2006).

Table 5.1. Mean air temperature anomalies at weather stations around the Barents Sea in December 2005 – January 2007, yearly mean anomaly in 2006, maximum anomalies and years when they were observed.

Station	Year/Month														2006 mean	Max/ Year
	2005	2006												2007		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan		
Spitsbergen airport	8.5	12.0	5.0	0.6	10.7	4.3	2.1	1.2	1.3	0.9	-0.3	4.9	6.0	5.6	4.3	4.3 2006
Bear Island	5.1	7.2	3.4	-1.5	6.3	2.9	2.8	2.0	1.7	0.9	0.4	3.2	5.7	3.3	2.9	2.9 2006
Tromsø	0.0	3.4	0.8	-2.5	2.1	1.8	-0.4	-1.3	0.4	0.9	-1.4	1.6	3.4	0.2	0.5	1.5 1938
Vardø	2.1	2.2	0.1	-0.1	3.5	2.0	2.1	0.3	0.6	0.2	-0.1	1.2	3.3	2.5	1.2	1.5 1937/ 2005
Murmansk	1.4	3.6	-0.9	-2.5	3.2	1.9	2.2	-0.8	0.9	-0.1	-	11.5	12.0	2.0	0.6	2.0 2005
Kanin Nos	2.2	0.2	-1.1	-0.3	2.3	2.0	2.9	-0.6	0.7	0.6	-0.3	-0.6	2.5	4.7	0.7	2.5 1937

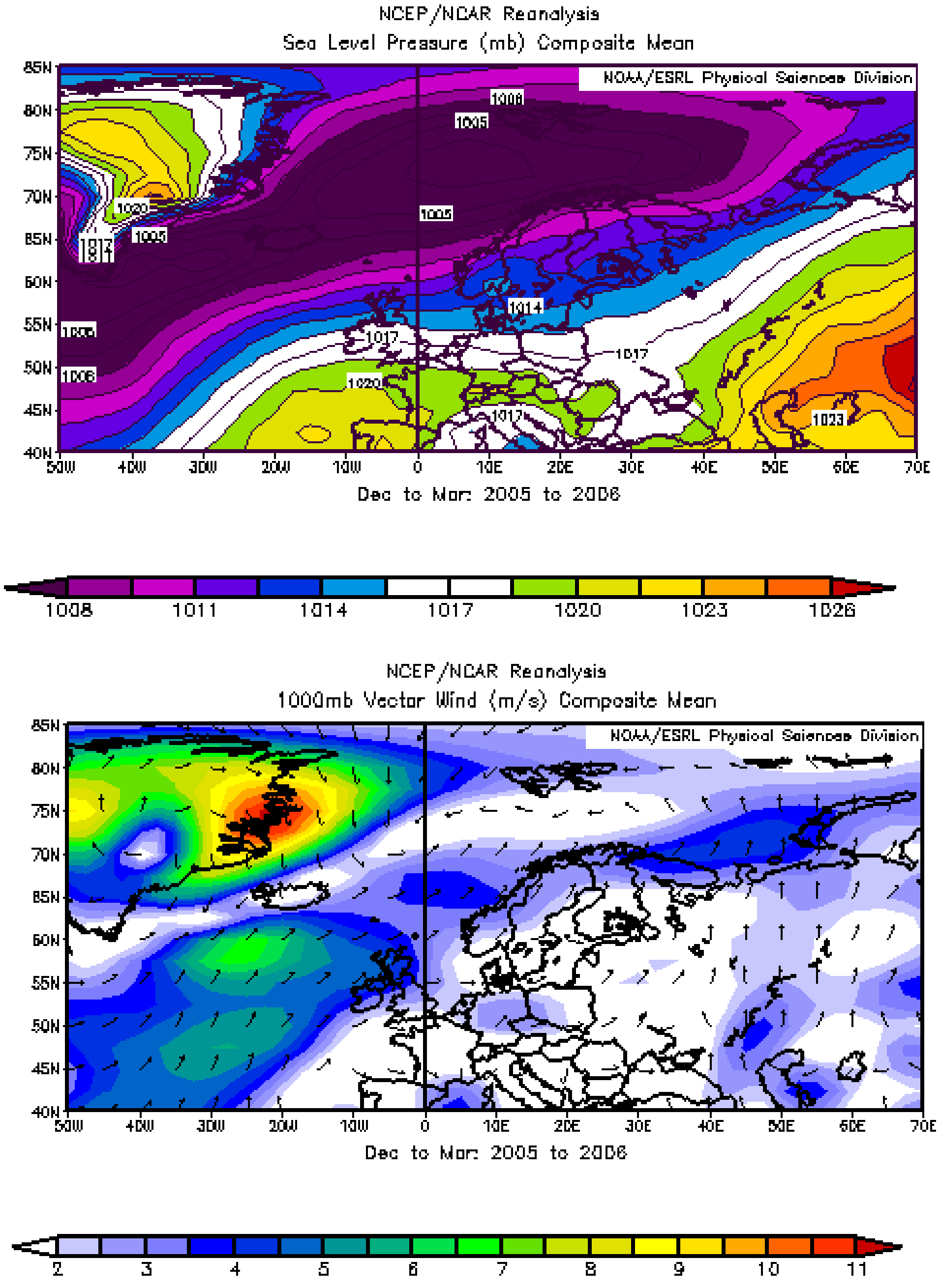


Figure 5.1. Sea level pressure (above) and wind vectors (below) in December-March 2005-2006.

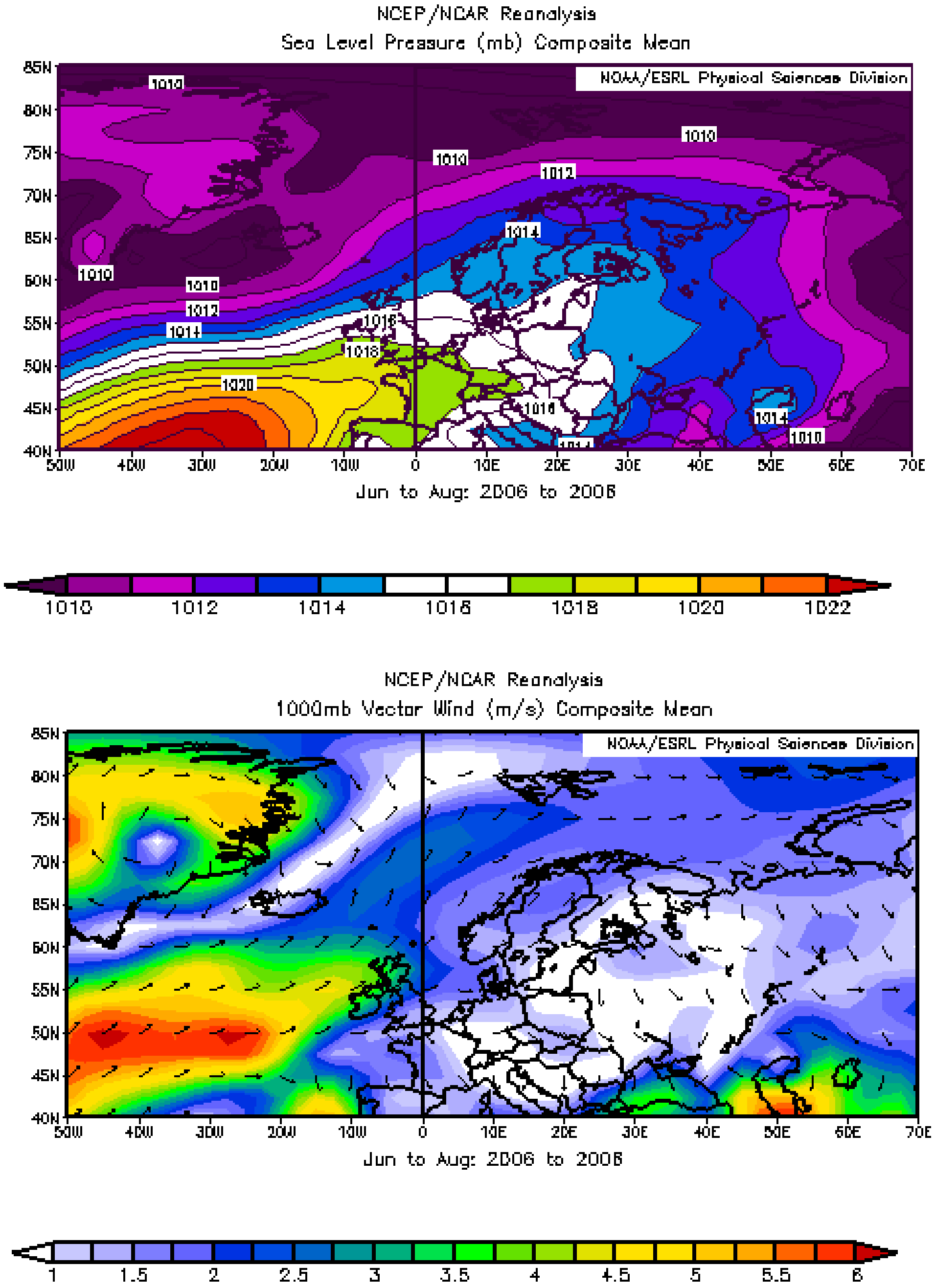


Figure 5.2. Sea level pressure (above) and wind vectors (below) in June-August 2006.

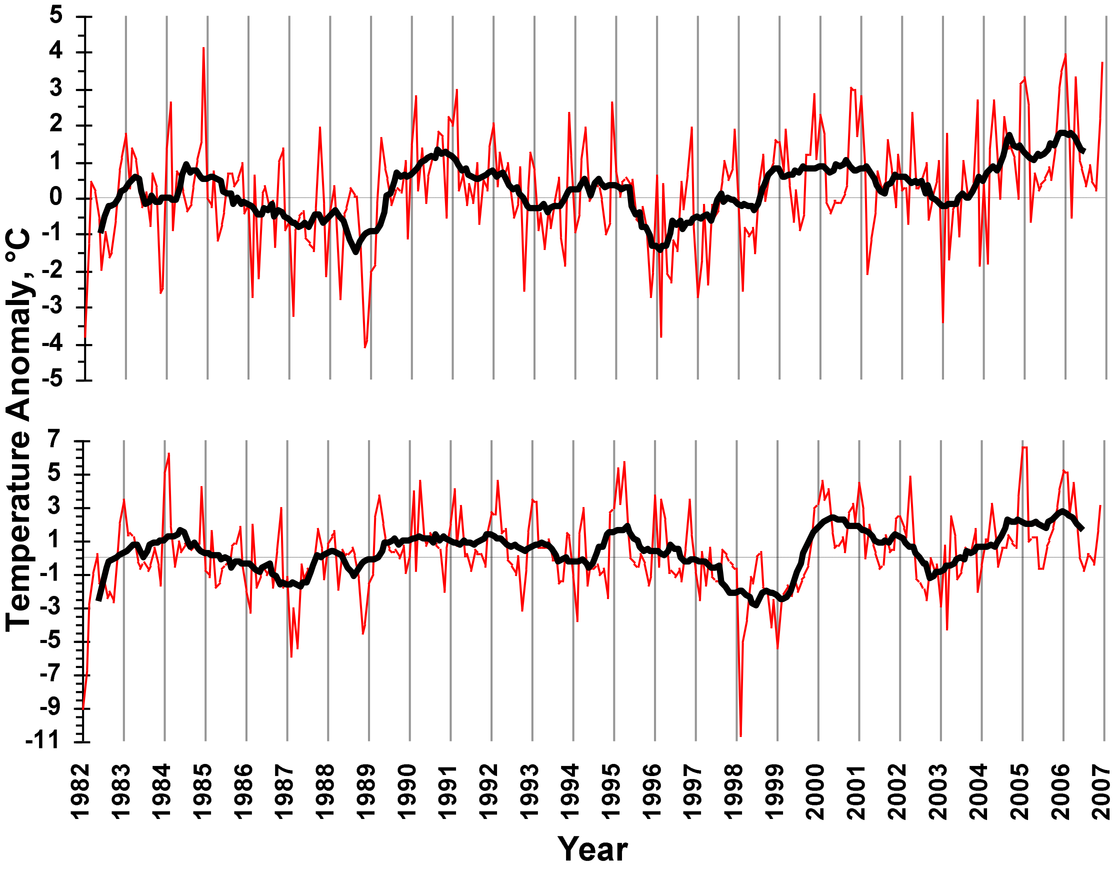


Figure 5.3. Air temperature anomalies over the western (above) and eastern (below) Barents Sea in 1982-2006.

5.2.2 Hydrographic conditions

5.2.2.1 Sea surface temperature

Sea surface temperature (SST) data were taken at http://iridl.ldeo.columbia.edu and averaged over the Bear Island – Spitsbergen area (74-79ºN, 08-25ºE), central (71-74ºN, 20-40ºE) and southeastern Barents Sea (69-73ºN, 42-55ºE). In 2006, over most of the Barents Sea area, SST was higher than normal, with maximum anomalies of 0.6-1.1ºC in the central and eastern areas (Figure 5.4). In May-June, the weakened radiation warming of the surface layer became a reason of decrease in SST anomalies. As a result, there was a transition from positive to negative SST anomalies in the western and eastern parts of the sea in July and in the central part – in August. In autumn-winter period, SST anomalies increased again to well above normal values. In that period, the maximum positive anomalies (1.0-1.3 ºC) were observed in the southern sea and reached.

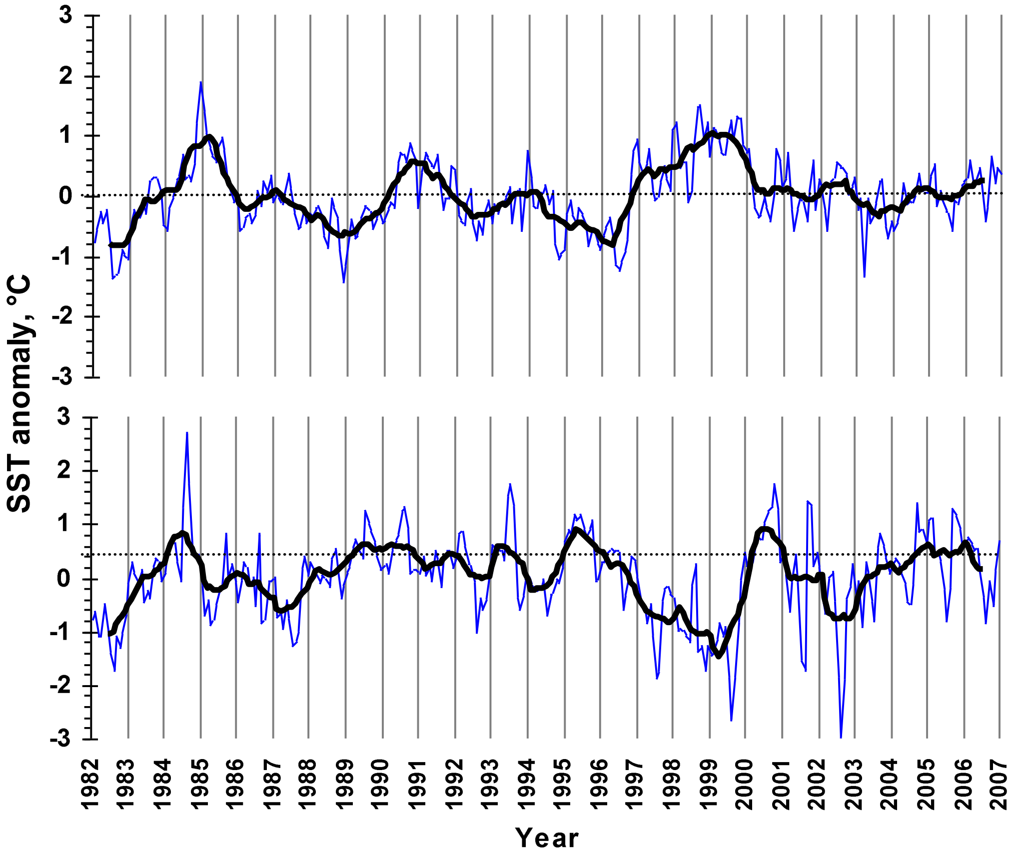


Figure 5.4. Sea surface temperature anomalies in the western (above) and eastern (below) Barents Sea in 1982-2006.

5.2.2.2 *Temperature in the standard sections, at 100 m and in the bottom layer*

The time series from the coastal waters at the fixed station Ingøy show that except for at surface in June-August, all temperatures were above the long-term mean (Figure 5.5). The highest deviations were in 250 m depth January-March 2006 when the anomlies were more than 2^{o}C.

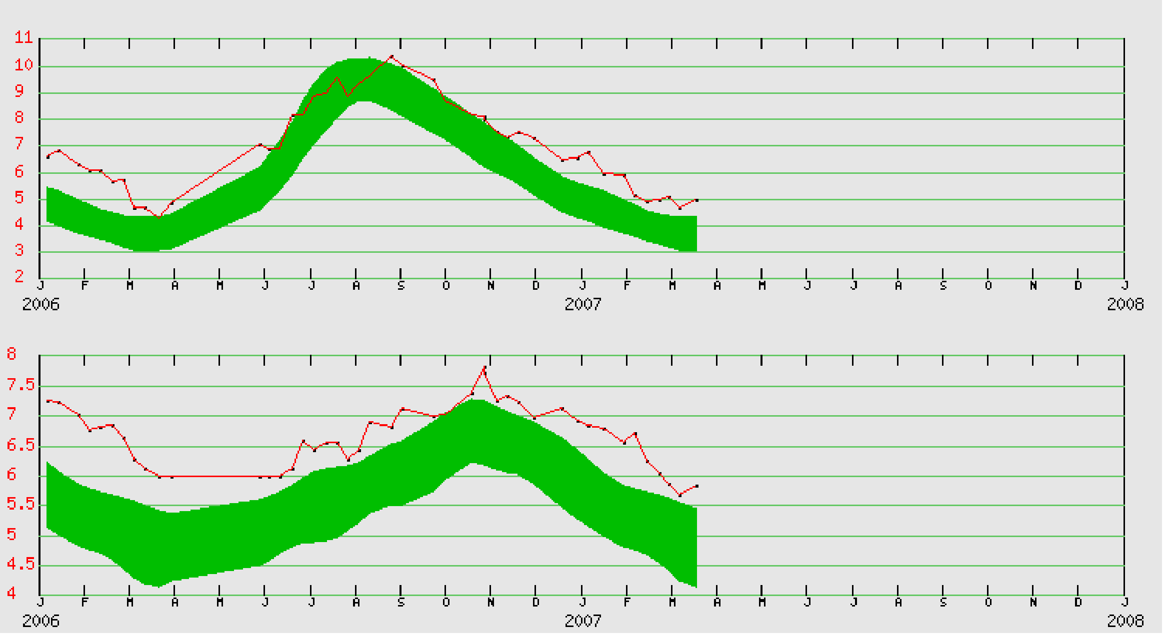


Figure 5.5. Temperature at 1 m and 250 m depth at the fixed station Ingøy, northern Norway, situated in the Coastal Current at the entrance to the Barents Sea. The red lines are the monthly means in 2006 and 2007. Vertical axis is temperatures (^oC) and horizontal axis is month. The green areas are the typical variations, +/- one standard deviation of the long-term average for the period 1936-1944 and 1968-1993.

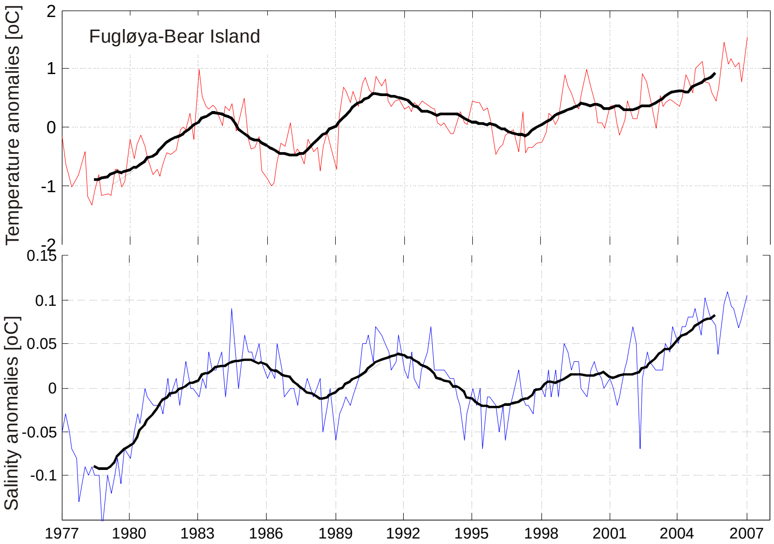


Figure 5.6. Temperature (upper) and salinity (lower) anomalies in the 50-200 m layer of the Fugløya-Bear Island section.

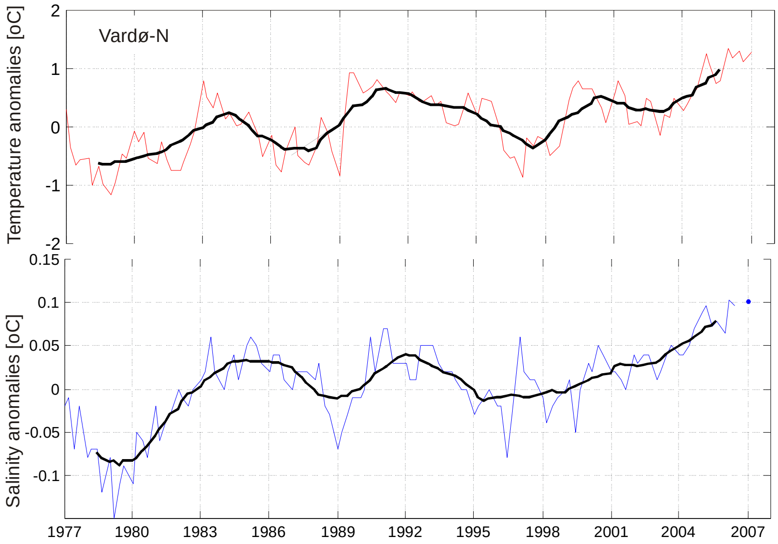


Figure 5.7. Temperature (upper) and salinity (lower) anomalies in the 50-200 m layer of theVardø-N section.

At the Fugløya-Bear Island section, a positive temperature anomaly of 1.44°C was observed in January 2006, and this is an all time high since the time series started in 1977 (Figure 5.6). The temperature stayed high throughout 2006, and all observations except October were all time high. In January 2007 the temperature anomaly was 1.55°C, a new all time high for this section. The salinity variations are similar to those in temperature, and there has been a high salinity in the last 6 years.

The Vardø-N section (Figure 5.7) shows much the same as the Fugløya-Bear Island section, but the anomalies are a smaller.

According to the observations of PINRO, in the Kola Section, which was made 9 times, sea temperature in the active layer (0-200 m) of the southern Barents Sea, was significantly higher than the long-term mean throughout the year, therefore 2006 can be considered as an anomalous warm year. From January to May, the temperature in the coastal waters (St. 1-3 of the Kola section) in all the layers was maximal during the whole period of observations since 1951, and in the Murman Current (St.3-7 of the Kola section), in 0-200 m and 50-200 m layers, the extremely high water temperatures were registered in the period from May to October (Figure 5.8). Since May, in the coastal waters, the positive anomalies were gradually decreasing. In 0-200 m layer, they decreased from 1.4 ºC to 0.6 ºC. In the Murman Current, some decrease of temperature anomaly was recorded from August to December, however throughout the year, it exceeded 1.0 ºC. (Figure 5.8).

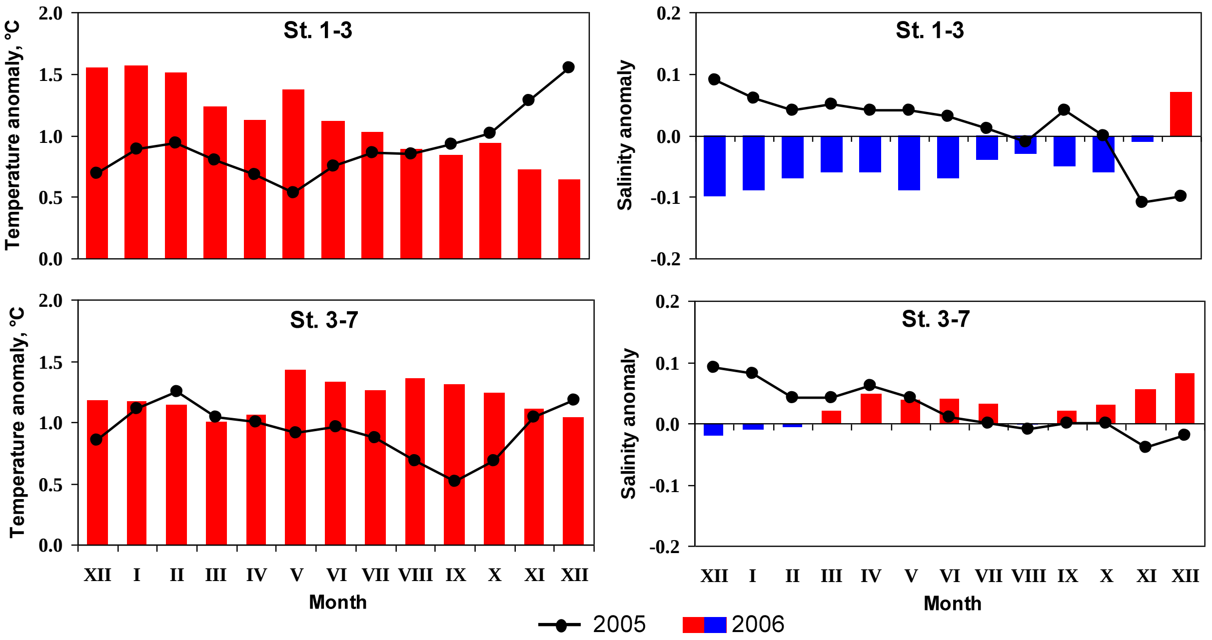


Figure 5.8. Monthly mean temperature (on the left) and salinity (on the right) anomalies in the 0-200 m layer of the Kola section in 2005 and 2006. St.1-3 – coastal waters. St.3-7 –Murman Current (Anon., 2007)

On the whole, it may be noticed that, in 2006, in the 0-200 m layer of the Kola section, the mean annual water temperature was highest on record for more than 100-year history of observations in the section. In the 0-200 m layer of the Murman Current, the salinity remained at the last year level, and, in the coastal waters, it was lower than normal and 2005 level (Figure 5.9).

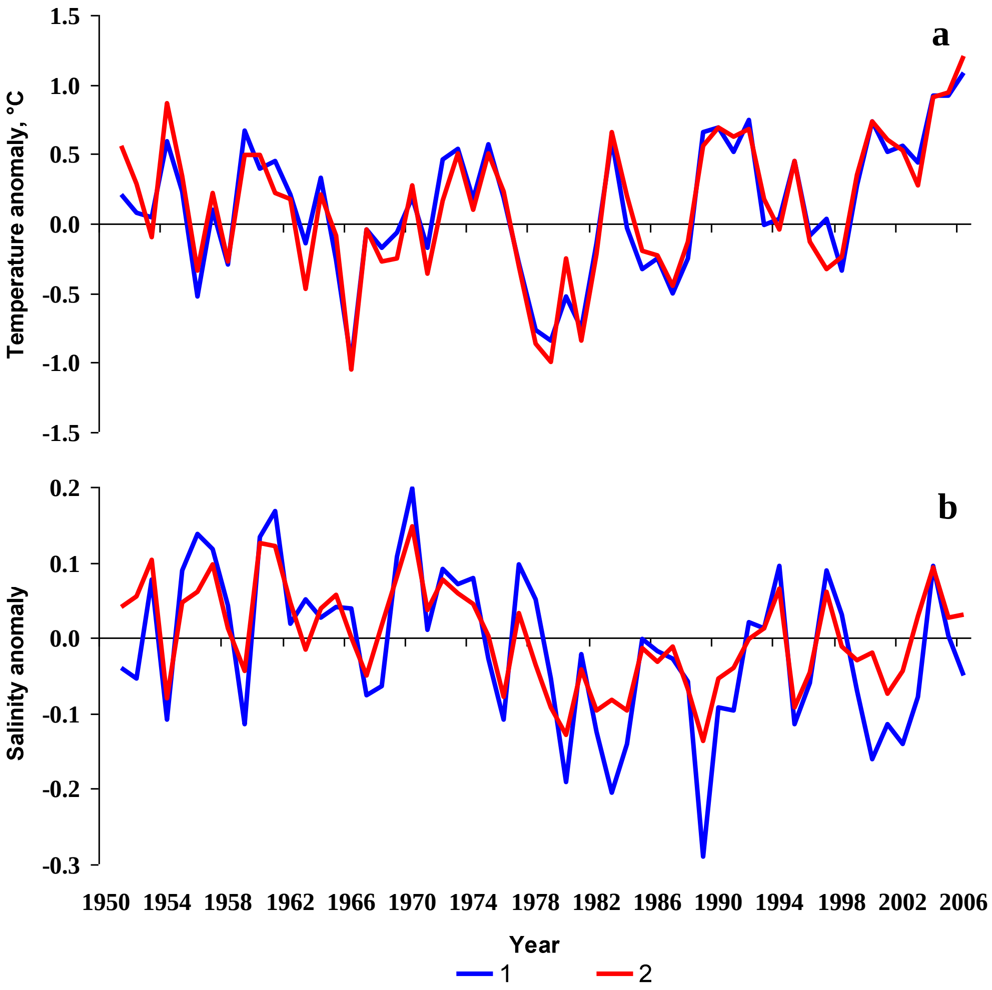


Figure 5.9. Mean annual temperature (a) and salinity (b) anomalies in the 0-200 m of the Kola section in 1951-2006. 1 – coastal waters, 2 –the Murman Current (Anon., 2007)

In the North Cape-Bear Island Section, the observations were made in May and September. Temperature of the North Cape Current area, in the 0-200 m layer, was characterized by significant positive anomalies: 1.3 ºC in May and 0.9 ºC in September.

In 2006, the section Bear Island – West (along 74º30'N) was occupied 5 times. During the year, temperature in the eastern branch of the Norwegian Current (74º30'N, 13º30'-15º55'E), in the 0-200 m layer, was significantly warmer than normal. The positive anomalies increased from 0.8 ºC in April to 1.3 ºC in October.

During 2006, the section Bear Island – East (along 74º30'N) was made 6 times. Temperature in the 0-200 m layer of the northern branch of the North Cape Current (74º30'N, 26º50'-31º20'E), significantly exceeded the long-term mean level, with the maximal positive anomaly (1.4ºC) registered in May and June. In August, the temperature of Atlantic waters remained high and, by October, positive anomalies of temperature decreased to 0.8 ºC.

In the eastern Barents Sea, in the Kanin section (along 43º15'E), the observations were made in August and October. In the Novaya Zemlya Current (71º00'- 71º40'N, 43º15'E), in the 0-200 m layer, water temperature was warmer than normal by 1.3 ºC in August and by 1.0 ºC in October.

In August-September 2006, there were warmer than normal in 100 m depth in most of the Barents Sea (Figure 5.10). The highest anomalies were observed in the northwesterly parts, with anomalies of more than 2°C, but in large parts of the Barents Sea the temperature was 1°C above the normal.

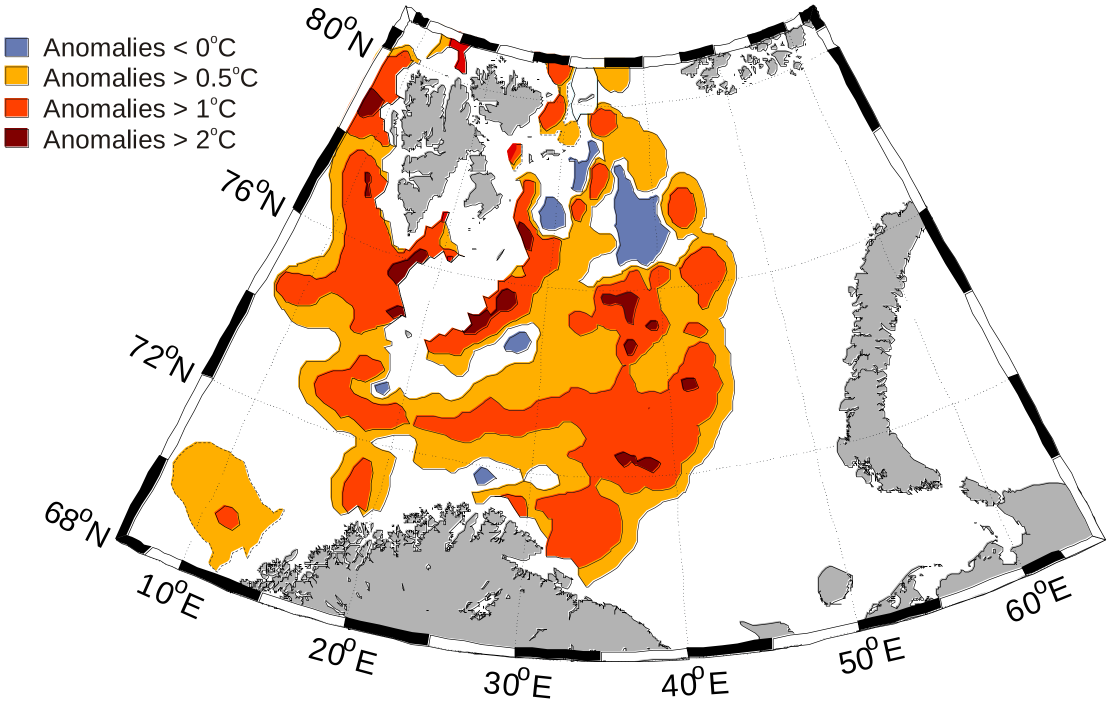


Figure 5.10. Temperature anomalies at 100 m depth in the Barents Sea in August-September 2006 (Anon., 2007). Data from the eastern Barents Sea are not included.

Also in the bottom layer of the Barents Sea, water temperature, on the whole, corresponded to that one in anomalous warm years. Waters with positive anomaly of bottom temperature occupied more than 80% of the surveyed area (Figure 5.11), and at about 30% of it, the anomalies were maximal for the period since 1951. The highest anomalies of temperature in bottom layer (over 3 ºC) were observed in the Spitsbergen Bank area. In the North Cape and Murman Currents, the positive anomalies of bottom temperature were 1.0-2.0 ºC. In the northeastern sea, the negative anomalies to 0.5 ºC were registered that was about 1 ºC lower than the last year level (Figure 5.11).

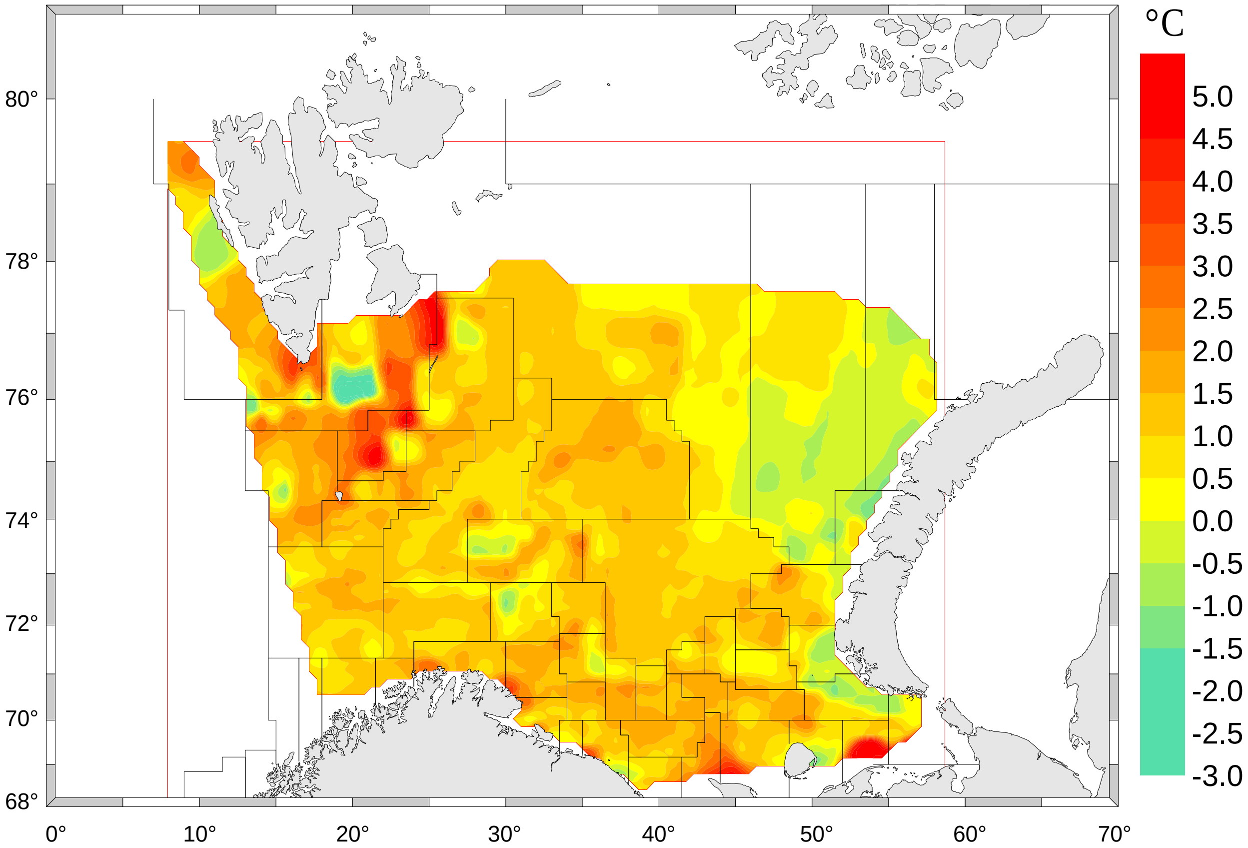


Figure 5.11. Bottom temperature anomalies in the Barents Sea in August-September 2006 (Anon., 2007).

In the southern Barents Sea, water salinity was typical of warm years. In the coastal waters, the decrease in salinity relative to both the long-term mean and the last year levels was observed. In the Murman Current, on the contrary, since March, some increase in salinity with reference to the long-term mean level and 2005 was recorded (Figure 5.8). In Fugløya-Bear Island and Vardø-N the salinity was record-high (Figure 5.6 and Figure 5.7). In August 2006 a significant part of the Atlantic water in the Fugløya-Bear Island section had salinities above 35.2, and in general all the Atlantic water in the section had salinities 0.1 above normal.

5.2.3 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. During the winter of 2006 the volume flux of Atlantic Water was the highest recorded since the observations started in 1997 (Figure 5.12). The inflow decreased towards spring, as it usually does in this area. This is also consistent with the modelled volume flux anomalies (Figure 5.13). The observational time series has for the moment only data until June 2006, but the modelled flux show that the inflow was relatively high also during the rest of 2006.

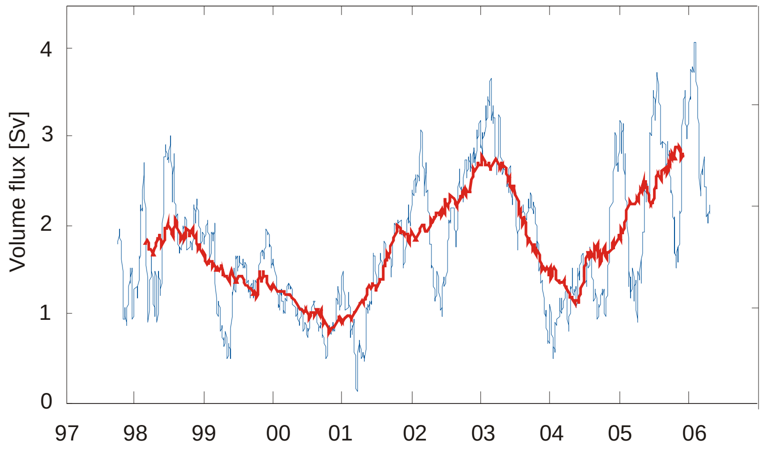


Figure 5.12. Observed Atlantic Water volume flux through the Fugløya-Bear Island section estimated from current meter moorings. Three months (blue line) and 12-months (red line) running means are shown.

There is a significant increasing trend in the observed volume flux from 1997 to summer 2006, and the calculated trend indicates that the mean Atlantic flux increased by almost 50%. The measurements started in a period with generally low inflow, but the increase is still stronger than expected.

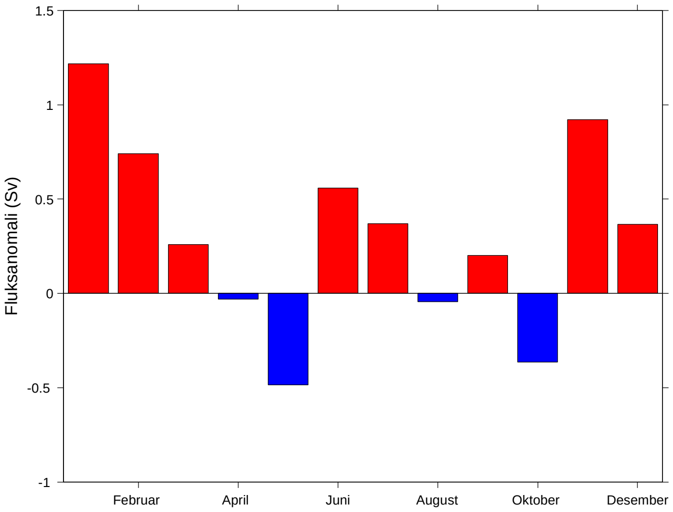


Figure 5.13. Modelled flux anomalies in 2006 through the section Fugløya-Bear Island. The anomalies are deviations from the long-term mean period 1955-2006.

5.2.4 Ice conditions

During the year, the sea ice extent was much less than the long-term mean, and, in January, May-July and December, it was the lowest for corresponding seasons since 1951. In 2006, the greatest ice coverage was observed in March and amounted to 44% that was 17% less than normal and the least – in August when there was no ice in the sea area. In the late September-October, with the prevalence of northerly and northeasterly winds and the decrease in air temperature the ice formation and shift southward became more actuated. In that period, the total ice extent increased to 10% (however, it remained being 7% lower than the long-term mean). In November-December, with the increase in the southern wind repeatability and high air temperature, the ice coverage again was at the level of significantly less than normal (Figure 5.14).

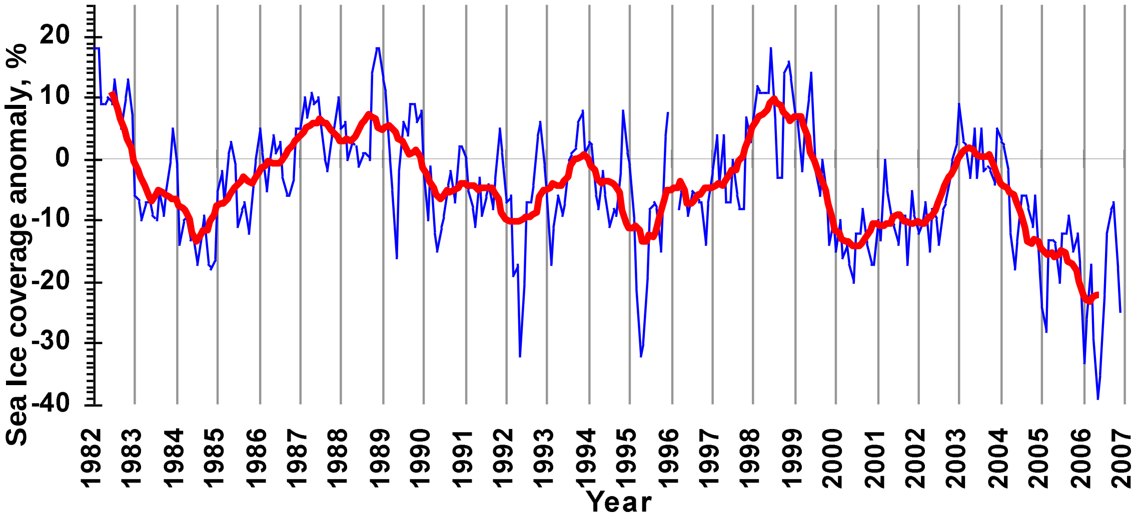


Figure 5.14. Anomalies of mean monthly ice extent in the Barents Sea in 1982-2006. A blue line shows monthly values, the red one – 11-month moving average values (Anon., 2007)

5.2.5 Expected situation

5.2.5.1 Temperature predictions

The natural first environmental parameter to try to forecast is sea temperature. Because the ocean has a ”long memory”, as compared to the atmosphere, it is 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 is often seen 2-3 years later in the Barents Sea. As the temperature decreased in the Norwegian Sea in 2002-2005, and considering the high temperatures in the Barents Sea in 2006, it is expected that 2007 will still be warm but colder than 2006. However, the expected decrease from 2006 to 2007 might be damped by a high volume flux into the Barents Sea.

A PINRO forecast model (Boitsov and Karsakov, 2005), based on harmonic analysis of the Kola section temperature time series, also predicts the temperature of warm Atlantic water of Murman current in 2007 to be higher than the mean long-term level, but most likely lower than 2006 (Table 5.2).

Table 5.2. Predicted temperature in the Kola section (0-200 m), representing the southern Barents Sea.

	Observation	Observation	Prognosis	Prognosis
Year	2005	2006	2007	2008
Temperature ^{o}C	4.8	5.1	4.6	4.5

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 adressed in chapter 5.10.

5.2.5.2 Expected ice conditions

Due to the extremely warm Atlantic waters in 2006 and beginning of 2007, in combination with the fact that the ice often lag the temperature variations with a few years, and the extreme ice minimum the recent years, the ice conditions in 2007 is expected to be low.

5.3 Phytoplankton

By E. K. Stenevik, L. J. Naustvoll and M. Skogen

5.3.1 Current situation

In 2006 low concentrations of phytoplankton was observed on the Fugløya-Bjørnøya in March, followed by a faint increase in diatoms close to Fugløya. In May, highest concentrations of chlorophyll on the Fugløya-Bjørnøya section were observed in the central parts of the section nd close to the coasts (Figure 5.15). Typical spring species of diatoms dominated in the central area. Close to Bjørnøya, the phytoplankton community was a mix of diatoms and Phaeocystis pouchetti, which is a common species in the Barents Sea during spring. In June (Figure 5.15), high concentrations of chlorophyll were observed on the stations close to Fugløya while lower concentrations were observed in the central part and also towards Bjørnøya. Diatoms (Chaetocerus) dominated in the area with high chlorophyll concentrations and this was most likely the last part of the spring bloom. Close to Bjørnøya Phaeocystis was the dominating phytoplankton species.

On the Vardø-north section there was a more even distribution of chlorophyll. On most stations a mix of phytoplankton species were observed in addition to microzooplankton. On the southern stations there were some diatoms with maximum concentrations below the surface (Figure 5.16) indicating that they were sinking.

During some years such as autumn 2005, large blooms of Emiliana huxleyi has been observed in the Barents Sea. This species was also observed in 2006 but in much lower concentrations than in 2005.

Simulations of the primary production in the Barents Sea using the ROMS numerical model showed that there was considerable interannual variation in timing of the spring bloom at the

Fugløya-Bjørnøya section during the years 1982 to 2006 (Figure 5.17). Even though we suspect the model to produce the bloom somewhat too early in the year, we expect the trends to be correct. The model results showed that the peak of the bloom may vary with about one month from year to year and in 2006 the results indicates that the bloom was relatively early. Figure 5.18 shows the timing of the bloom throughout the Barents Sea in 2006. It shows that the bloom was earliest at the western entrance of the Barents Sea. Also close to some of the bank areas, the bloom started early. Particularly in the eastern part close to Goose Bank and North Kanin Bank but also at the Central Bank and the Svalbard Bank. 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.

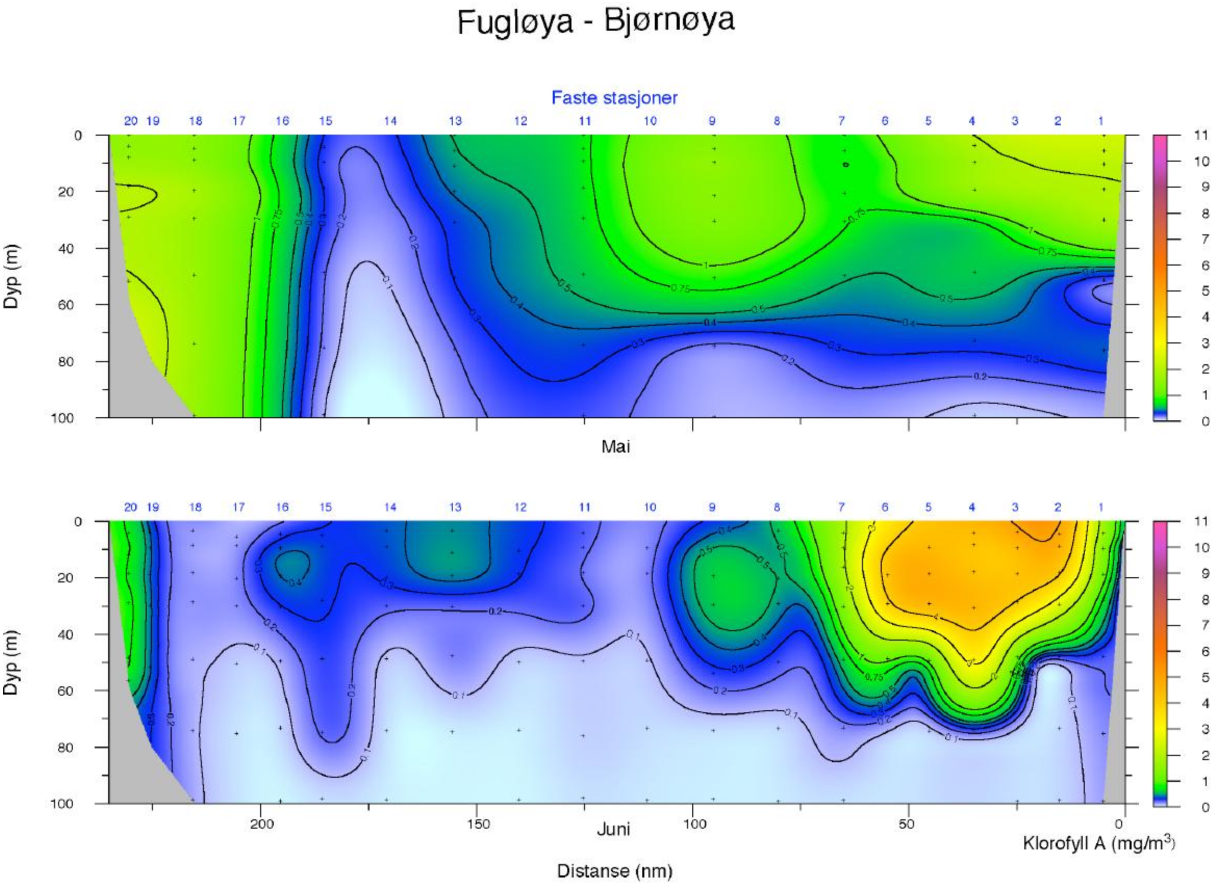


Figure 5.15. Measured chlorophyll in the upper 100 m on the transect Fugløya – Bjørnøya in May and June. North to the left.

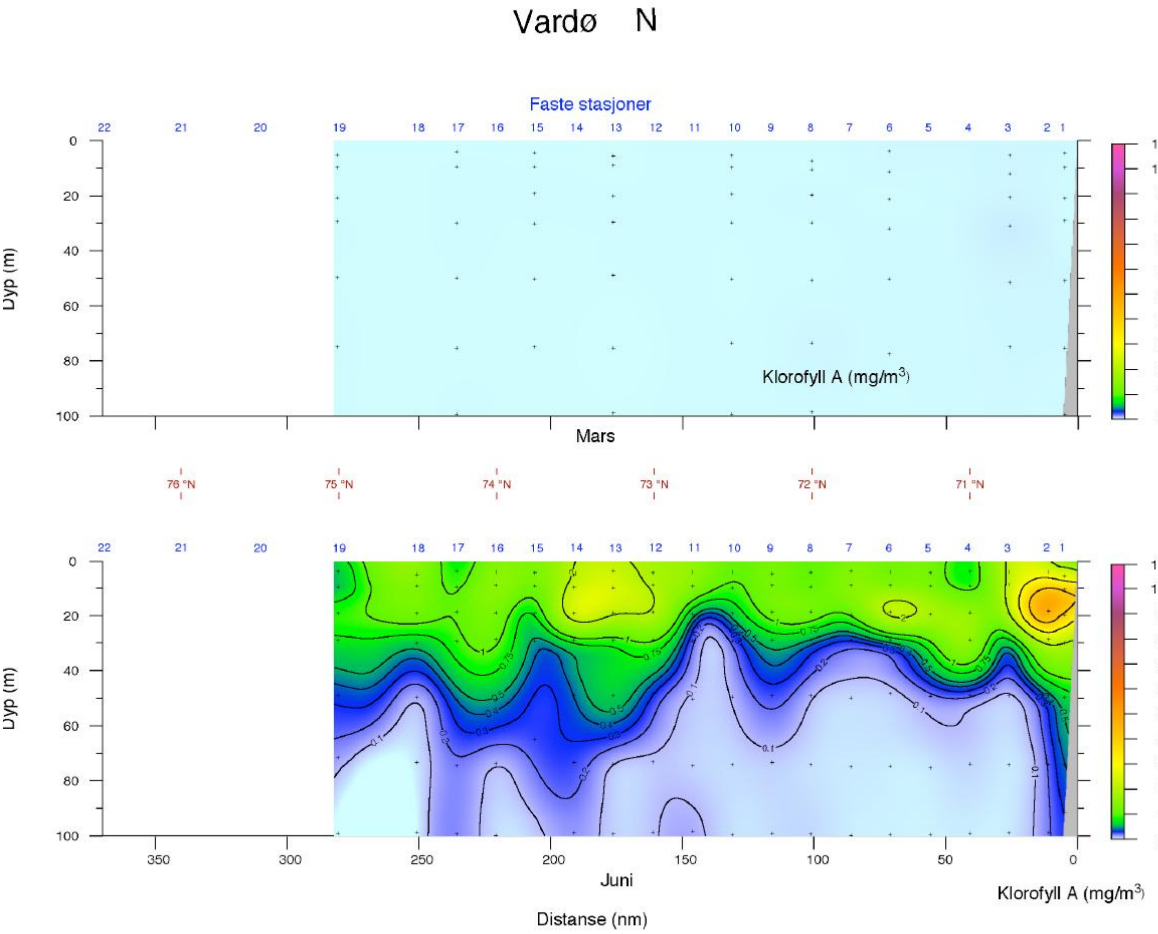


Figure 5.16. Measured chlorophyll in the upper 100 m on the transect Vardøy north in March and June. North to the left.

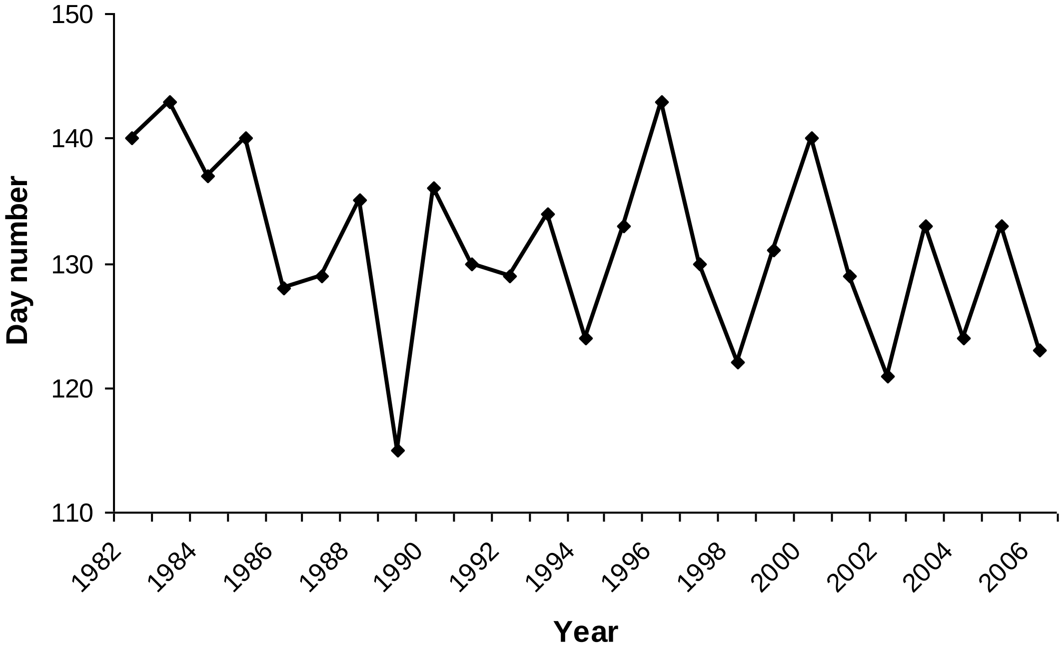


Figure 5.17. Modelled day number of peak diatom spring bloom at the Fugløya-Bjørnøya section during the period 1982 to 2006 using the ROMS numerical model.

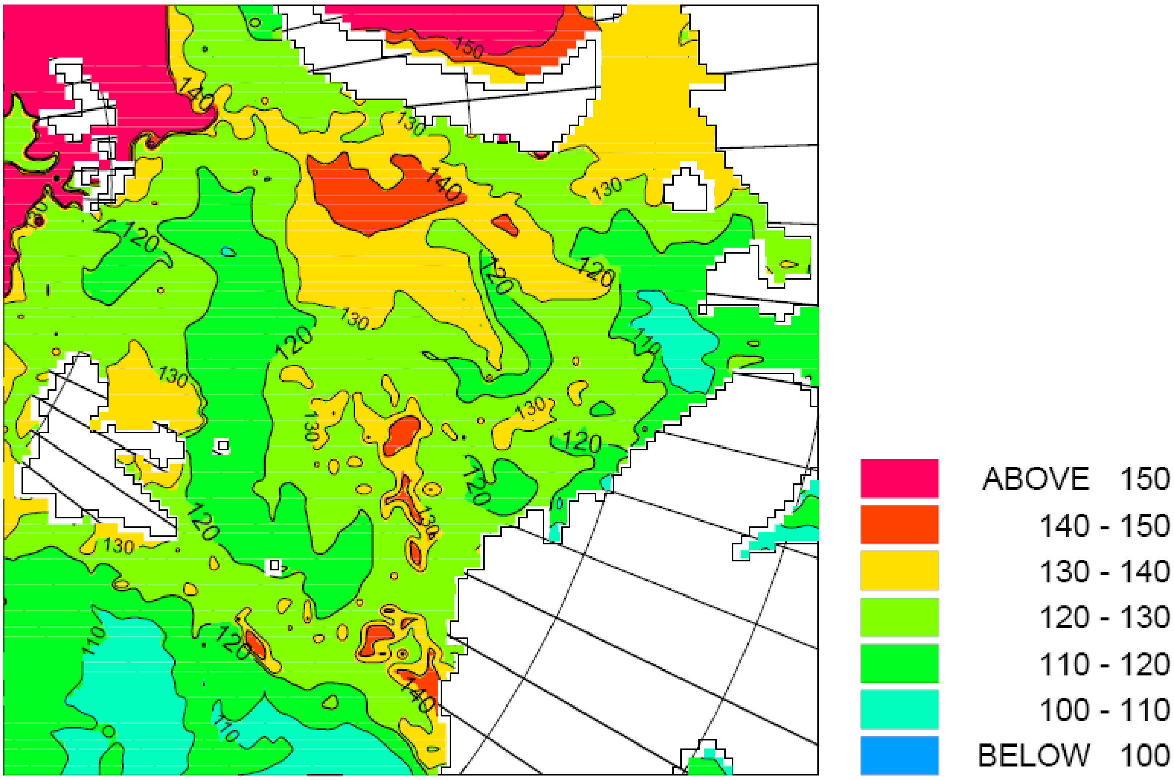


Figure 5.18. Modelled day number of peak diatom spring bloom in 2006 using the ROMS numerical model.

5.3.2 Expected situation

With the present knowledge it is not possible to predict whether the onset of the spring boom or which algae's that will dominate the system. In addition to available nutrients the onset of the spring boom depends heavily on factors such as stratification and light. Stratification depends further on solar heating (again dependant on cloud cover) and wind mixing, while the light conditions depends on the cloud covers, which are factors that change on very short timescale.

5.4 Zooplankton

By T. Knutsen, P. Dalpadado and E. L. Orlova

5.4.1 Current situation

In 2006 the average zooplankton biomass was above average in the Barents Sea. From 2005 to 2006 there was observed an increase in average biomass from 7. 7 to 8.6 g dryweight m^{-2} (Figure 2.10, upper panel), measured for the whole water column for stations less then 500 m deep. The average values for 2006 are based on 150 stations relatively homogeneously distributed in the region. Visual examination of the zooplankton composition indicated predominance of the three *Calanus* species (*Calanus finmarchicus, Calanus glacialis and Calanus hyperboreus*) at later stages of development, *euphausiids* and *chaetognaths*, and in some cases *pteropods*, that caused high biomass estimates.

Figure 5.19 shows the horizontal distribution of mesozooplankton from bottom-0 m, using the combined data sampled by WP2-net (used by Norway) and Juday net (used by Russia). The Russian and Norwegian data complement each other. The distribution of zooplankton biomass based on joint Norwegian and Russian biomass data is near identical to that observed during the Norwegian surveys, but Russian data add significant information particularly for the eastern regions of the Barents Sea.

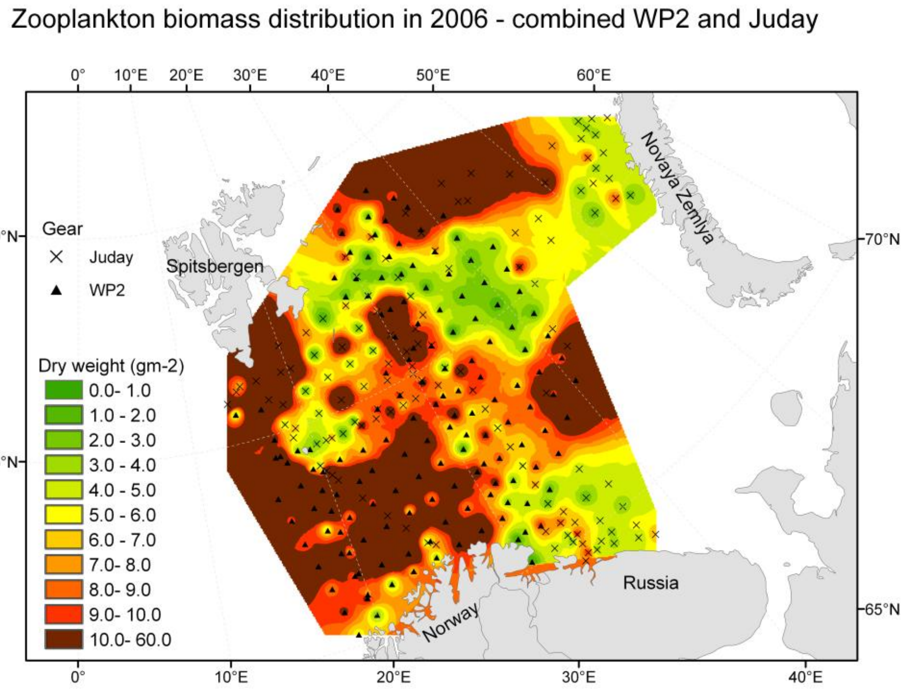


Figure 5.19. Distribution of zooplankton dry weight (g m^{-2}) from bottom-0 m in 2006. Combined data for WP2 and Russian Juday net samples.

The plankton distribution in 2006 is quite similar to 2005. The highest abundances of plankton were observed in the western part of the Barents Sea and in the central northern part of the region. In 2005, a low abundance region in the south was observed, extending northwards a significant distance from the Norwegian coast. Such a situation could not be observed in 2006. The southern and western distribution of high zooplankton biomass in 2006 is probably associated with influx of warmer Atlantic water penetrating north and east into Bjørnøyrenna, resulting in higher zooplankton concentrations here compared to 2005. Figure 5.19 shows lower zooplankton concentration in a small region east of Bjørnøya, an area influenced by Arctic water masses. The region closest to the Norwegian coast had somewhat lower zooplankton biomass. In the most northern part of the survey area, again high zooplankton abundance was recorded, caused by high occurrence of the amphipod *Themisto libellula* and the copepods *Calanus hyperboreus* and *C. glacialis.* South and south-east of this area a region showing low zooplankton abundance was observed, an area influenced by colder Arctic mixed waters. The importance of water mass characteristics on zooplankton abundance is shown in Table 5.3. It is apparent that zooplankton abundance on average is highest in Atlantic water masses with 11.3 g dry-weight m^{-2} (compared to 9.6 g dry-weight m^{-2} in 2005). The low biomass observed in coastal water masses can be due to low coverage in terms of number of stations (four stations only), but it corresponds to what was found in the same water mass in 2005.

C. finmarchicus being predominant in copepod concentrations were mostly represented by copepodites of III-V stages and *C. glacialis* development stage III, while nauplia and eggs of *Copepoda* occurred fairly rarely. This evidenced that their reproduction had almost completed and in boreal species the annual cycle of development was close to the end, while Arctic species were in the process of fat accumulation before the onset of the wintering period. Wide variations in the abundance of the above species, to almost complete absence in catches at some stations, also reflected their changes in vertical distribution throughout 24 hours.

Table 5.3. Zooplankton average dry weight (g m^{-2}) in different watermass categories in 2006. Combined data for WP2 and MOCNESS (Norwegian data only).

	No stations	Average dry weight (g m^{-2})	Standard deviation
North Atlantic water	110	11.3	7.9
Coast water	4	1.6	1.6
Coast/North Atlantic water	19	7.3	3.7
Arctic water	21	8.5	4.3
Polar front water	34	5.0	5.1

Thus, data obtained on zooplankton in 2006 in the eastern areas of the Barents Sea allowed its description from different sides. This was an anomalous warm year, close to the conditions as observed in 2005, when in the Barents Sea there was no ice from the end of July to September and in warm season distribution of both Atlantic waters and waters of the warm Novaya Zemlya Current was more northerly than usual. In the northeastern areas of the sea in this period the sea surface temperature was positive, which was indicative of high heat content in the Arctic waters. In the second half of September zooplankton was represented mostly by oceanic forms, by both permanent inhabitants of the Atlantic and Arctic waters like *Copepoda, Amphipoda* and *Euphausiacea* and temporal ones such as *Polychaeta, Cirripedia, Bivalvia, Decapoda* and *Echinodermata.* In the first area located more southerly, abundance of copepods was higher but due to domination of Arctic species (*C. glacialis* and especially *M. longa*), the percentage of the boreal *C. finmarchicus* was slightly above 50%. In the population of euphausids, except for northern areas, higher abundance of Arcto-boreal species (*T. inermis* and *T. longicaudata*) was also noted. As for hyperiids, only *T. abyssorum,* a relatively warm-water species, was observed in large numbers. Cold-water representatives of *Pteropoda* and *Chaetognatha* were not numerous.

In the second, more northerly area, composition of plankton was mixed. In this area, wider distribution was noted for Arctic species but *C. glacialis*, compared to the first area, was a little less abundant, while the abundance of *M. longa* was twice lower. At the same time *C. hyperboreus* was reasonably abundant, and the overall percentage of *C. finmarchicus* exceeded 60%. However, on the whole in the above indicated areas when compared to other warm years (1983, 1989), the percentage of *C. finmarchicus* decreased from 75-85% (Orlova *et al.*, 2004) to 52-63%, while the proportion of *C. glacialis* remained at the previous level (15-18%). The percentage of *M. longa* increased (up to 18-32%). In this area, high abundance was also registered for other cold-water representatives of macroplankton: *Thysanoessa raschii, Clione limacina, Limacina helicina*, as well as Arctic hyperiid *T. libellula*, which in the first area did not occur at all.

5.4.1.1 *Fugløya-Bear Island transect*

The mean zooplankton biomass along the FB section (1994-2006) is very low during the winter months (Figure 5.20a,b). Very little zooplankton average biomass (0.44g m^{-2}) was observed in the upper 100m during winter during these years. A low biomass was also observed from bottom-0 m (1.72 gm^{-2}), indicating that the production is quite low in winter and that the majority of zooplankton stays in the deeper part of the water column. In summer, the biomass in the upper 100 m (mean =5.38 g m^{-2}) varied little except for 1994, where one station contributed to the very high mean biomass. The average biomass in spring/summer for the whole water column was 7.8 g m^{-2}. The average biomass increased from 3.9 in 2005 to 6.4 gm^{-2} in 2006, with the 2006 value exceeding the long-term (1994-2006) average of 5.4 g m^{-2}.

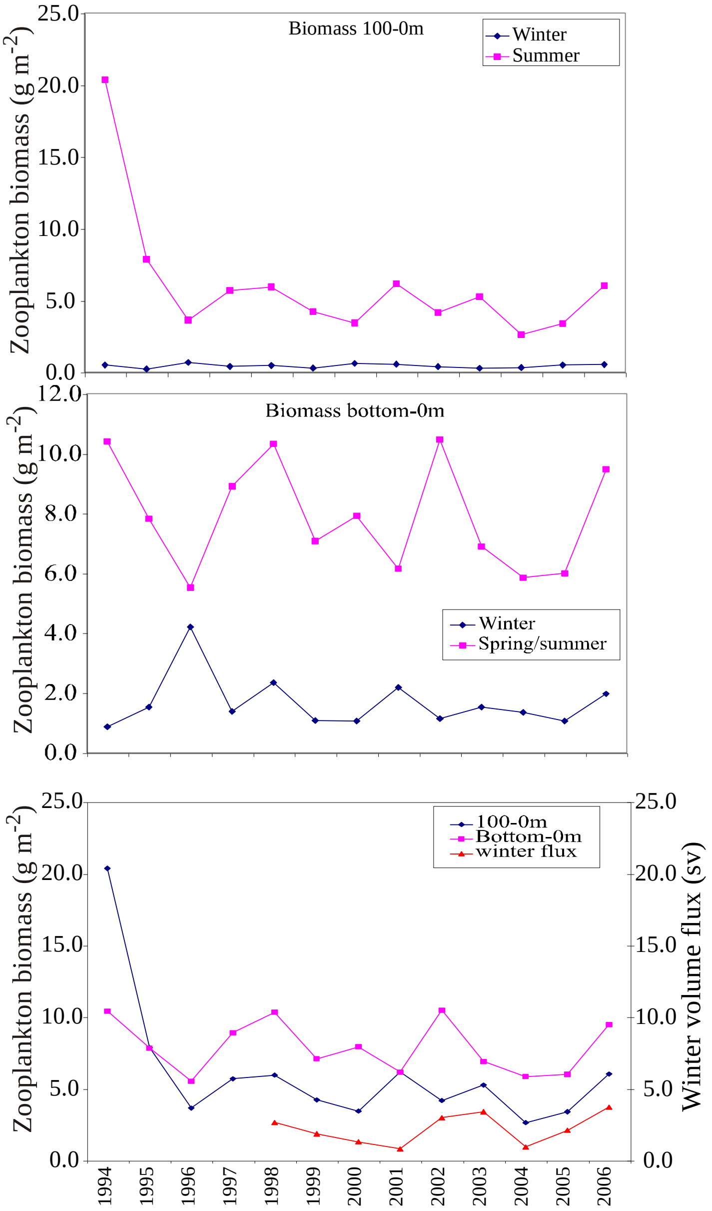


Figure 5.20. Mean annual zooplankton biomass (gm-2 dry weight) in the Fugløya-Bear Island transect a) 100-0m, and b) bottom-surface during winter (January-March) and spring/summer (May-August), c) Spring/summer biomass together in upper 100m with winter (January-March) Atlantic flux, from bottom-surface.

Current moorings deployed at the FB section measure the inflow of Atlantic water at the western entrance to the Barents Sea (Ingvaldsen et al., 2004, updated to 2006). The winter flow given in Figure 5.20c is from December to March, measured for the whole water column. The biomass changes in spring and summer seem to be closely linked to the winter inflow (Figure 5.20c). By March, the zooplankton and particularly *Calanus finmarchicus* has already started to rise from its over-wintering habitats in the deeper part of the Norwegian Sea and these organisms are probably in a position to be advected with the Atlantic flow into the Barents Sea. The temperature conditions in the Barents Sea are related to the Atlantic flow, thus providing warmer conditions when the flow is high or water are warmer then normal (Ingvaldsen et al 2004). Temperature conditions and the advection most probably play an important role in regulating the zooplankton biomass in the Barents Sea. The data from 2006 supports the notion that increased influx of warmer water help maintain a high zooplankton biomass in the Barents Sea.

5.4.1.2 Autumn-winter macroplankton survey

The survey conducted in autumn and winter reflects the expected situation in the beginning of next year and hence the reproductive potential of krill. The autum 2005 survey showed that the abundance of pre-spawning euphausids in the beginning of 2006 was almost by 1.5 times higher than the long-term mean in both southern and the north-west area of the sea.

An increase in abundance of euphausids was observed in the central, coastal and northwestern areas of the sea (Figure 5.21), while in the eastern and western parts a slight decrease abundance was observed. It is worth noting, that since 2002 in the eastern areas high abundance of euphausid has been observed to be stable. High level of euphausid abundance in these areas was registered in the warm periods of 1970’s, 1980’s and 1990’s (Orlova *et al.*, 2005).

The densest local concentrations (>5000 ind./1000m^3) of euphausids were found to the east of the Bear Island (Figure 5.22), on the northern slope of the Goose Bank and in the northern part of the Novaya Zemlya shallow waters. Dense concentrations of euphausids (1000-5000 ind./1000m^3) were located in the northwestern areas, as well as in the southern part of the sea.

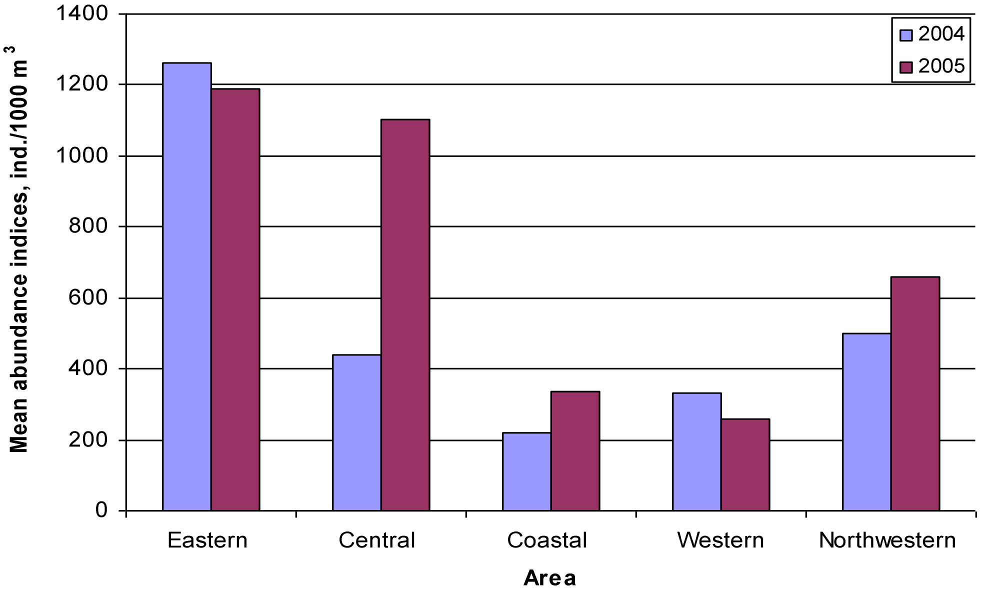


Figure 5.21. Mean abundance indices of euphausids in autumn 2004 and 2005.

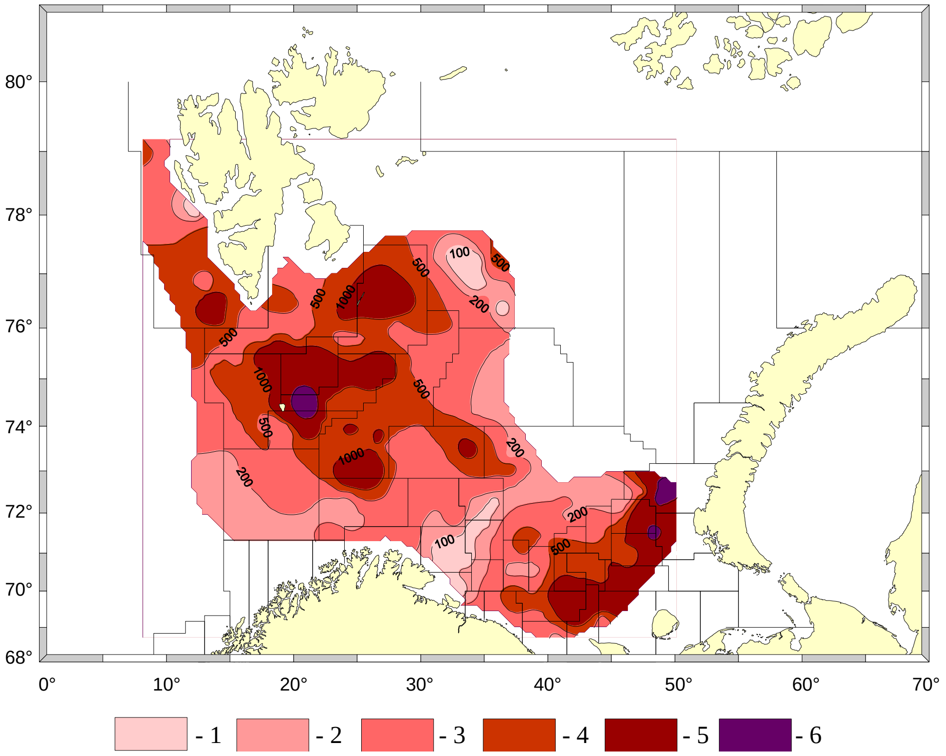


Figure 5.22. Density of bottom concentrations of euphausids (ind./ 1000m^3) in autumn 2005: 1 – 1-100, 2 – 101-200, 3 – 201-500, 4 – 501-1000, 5 – 1001-5000, 6 – more than 5000.

Species composition of euphausiid was normal. The northwestern areas was dominated by *Thysanoessa inermis* (96% of total abundance in samples), while in the central areas the proportion of *T. raschii* and *T. inermis* were 68% and 24%, respectively. In the eastern areas catches were dominated by *T. raschii (*85%), while *T. inermis* constituted 13% (relative weight).

The proportion of the warm-water species *Meganyctiphanes norvegica* in the euphausid concentrations remained at the same level compared to the previous year. The main distribution area of the species was west of the Bear Island, as well as the southearstern part of the sea.

Thouth, as in previous years, the main concentrations of euphausids were formed by Arcto-boreal species *T. inermis* and *T. raschii*; samples included euphausids of the three age groups (0+, 1+ and 2+) being 8-40 mm long. The rest of species: *T. longicaudata*, *T. raschii*, *M. norvegica* and *N. megalops* made up a minor supplement.

5.4.2 Expected situation

Taking into consideration the hydrographic conditions and the long-term dynamics of zooplankton development, the spawning of the main zooplankton organisms (copepods and euphausiids) in 2007 in the southwestern areas of the Barents Sea is expected to start in the middle of April. Having overwintered, these groups of crustaceans, along with the warmwater species transported from the Norwegian Sea, will contribute to the establishment of zones with high density of zooplankton in the northwestern and western sea areas. As a result the food supply for pelagic predators will most probably be good. In late May-June euphausiids will descend to the bottom layers where they are more available as feedfor adult cod.

It is expected that 2007 will be similar to 2006 with regard to the distribution and periods of forming fish feeding area by plankton. Hence, it will most probably provide good feeding conditions for capelin, herring and juvenile fish. However, a significant uncertainty exist with respect to the recovery of capelin, the development of the blue whiting and herring stocks and how this might influence the growth in zooplankton stocks.

The average zooplankton biomass measured in August-September 2006 (8.6 g dry weight m^{-2}) was above the long-term mean (7.14 g dry weight m^{-2}), and has slightly increased since 2001 (5.85 g dry weight m^{-2}). Atlantic water masses contain the highest biomass, stressing the importance of advective transport of zooplankton from the Norwegian Sea, and the favourable higher temperatures in these waters that significantly influences the central and western part of the Barents Sea. The adult capelin stock was still very low in 2006. Other plankton consumers like juvenile cod, capelin, haddock and redfish are important, but particularly young herring which has been very abundant the last few years, surely influence zooplankton biomass. Additional species such as blue whiting and sandeel, now seem to extend their distribution range in the Barents Sea, hence their predation pressure on zooplankton can be expected to increase. The average zooplankton abundance in 2006 suggests that the conditions for local production are favourable for 2007, and slightly improved with respect to 2006.

5.5 Benthos

By L.L. Jørgensen, N. A. Anisimova, P. A. Liubin, I. E. Manushin and J. Sundet

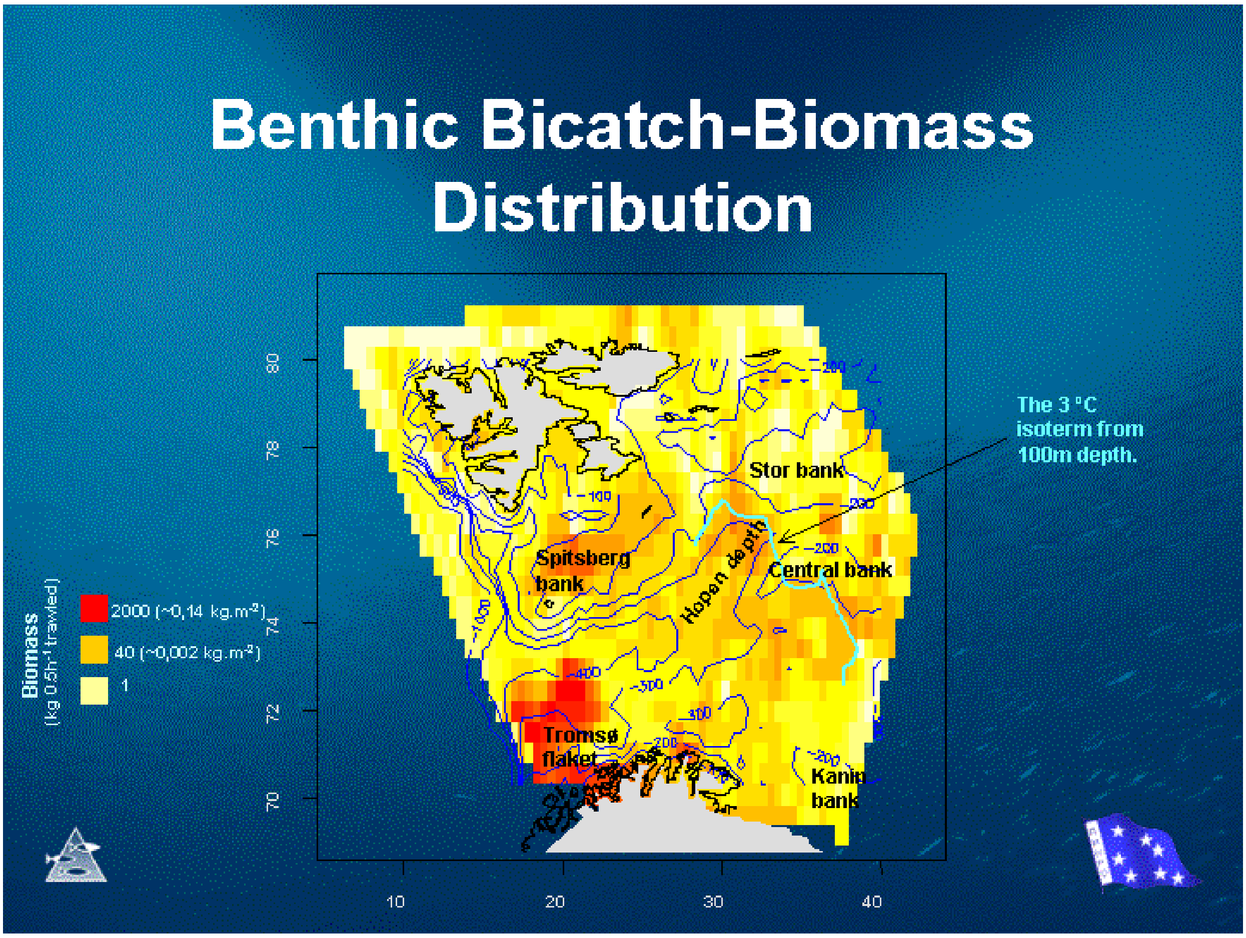
5.5.1 Current situation

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. The bottom dwellers are called “epibenthos”. A large amount of these species are large, conspicuous and robust organisms including sea stars, brittle stars, sea cucumbers, sea lilies, crangonid prawns, isopods, sponges, corals, mollusks and sea anemones. We call these group “mega epibenthos”.

Several species of this group of animals shows limited movement and have a long life span. Therefore, they are expected to be found in the same areas year after year. By-catch in bottom trawling includes mega-epibenthos, because they are easy to catch with such equipment.

By-catch investigations indicate that the current distribution of megabenthos in the Barents Sea is highly variable from area to area (Figure 5.23). The biomass-hotspots seem to be localized at the Tromsø Flake (mainly sponges), in the Hopen Deep (mainly prawns) on the Spitsberg Bank and in an area south of the 3°C isotherm, indicating the northern distribution of Atlantic water (the polar front).

Previous studies indicate that understanding the patterns of benthic fauna in the Barents Sea is based in a large part on the bathymetric features and the distribution of sediment (Wassmann et al 2006). These studies has combined benthic data from large scale Russian expeditions from 1930´s to 1990´s showing that the benthic biomass had great spatial variation, ranging from <10 to >500g WW m^{-2} and where the highest biomasses occurs in the shallows of the Spitsbergen and Central Banks and in banks of the Russian Zone. These high biomass values was connected to a possible high primary production at the western Banks, combined with strong water currents in these areas to resuspend food materials and hard substrate supporting high proportions of sessile filter feeders.



Benthic Bicatch-Biomass Distribution

The 3 °C isoterm from 100m depth.

Figure 5.23. Bottom fauna by-catch in kg, per 0.5 h trawling (~13.500m^2), in August-September 2006. The weight data for the survey area were obtained by linear interpolation of the sampling stations estimates (log transformed). The light-blue line depicts the 3 ℃ isotherm at 100 m depth, indicating the northern distribution of Atlantic water. The dark-blue lines indicate depths in meters.

A closer analyse (Figure 5.24) of the total megafauna by-catch, shows that sponges made up the larges biomass (11.5 tonnes, 41 % of the total catch of 789 stations). This sponge hotspot of 140g wet weight per m^2 (this weight does not include other associated animals) was mainly recorded in the southwestern part of the Barents Sea (see also Figure 5.23). Crustaceans (including prawns, crabs, and squat lobsters) made up 33 % (9.3 tonnes) of the total catch and were mainly made up by deep sea prawn (*Pandalus borealis*) in the Hopen-depth, and king crabs *(Paralithodes camtschtica)* in the southeaster Russian zone of the Barents Sea. Echinodermata (including sea stars, sea urchins, brittle stars, sea cucumbers and sea lilies) made up 50 % (2.5 tonnes) of the catch. These three, main mega-epibenthic, animal groups were followed in biomass by Tunicates (sea squirts), Cnidaria (sea anemones, corals and hydroids) and Mollusca (snails, bivalves, cuttlefish/squids). Then several small groups were represented in varying amounts from 0.2 – 0.005 %.

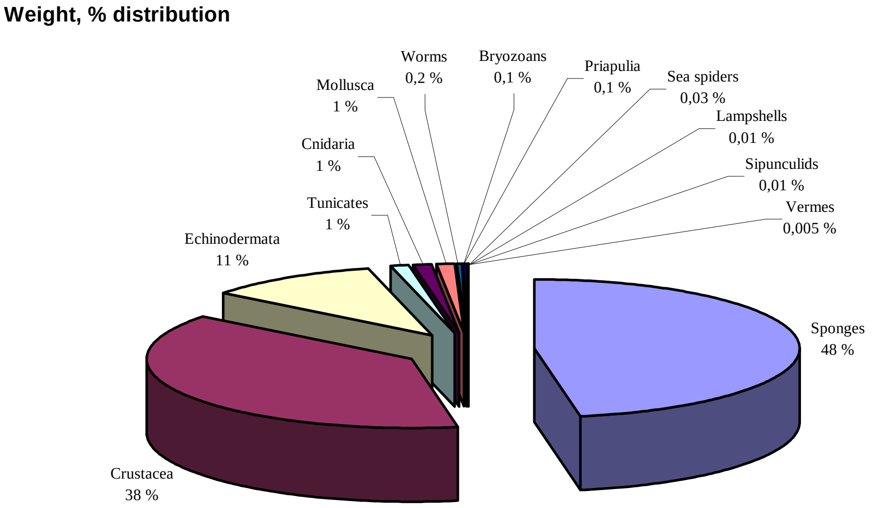


Figure 5.24. The main taxagroups of mega epibenthos presented as the % distribution of wet weight, taken as by-catch in August September 2006 from 789 stations in the Barents Sea.

Taken a closer look at one of the main epibenhic animal groups, the Echinoderms (Figure 5.25), the distribution of the taxas shows that the sea stars are widely distribution, though having a biomass hotspot in the northern Hopen depth and in eastern Barents Sea. Compared to the biomass of sea stars, are the sea urchins (small individuals) relatively sparsely represented, and mainly in eastern and western parts of the Barents Sea. This was also the case with the brittle stars, which was mainly to be found in eastern Barents Sea.

Sea cucumbers were, as the sea stars, made up by large individuals (10-25 cm body length) and were recorded in large biomasses in the Northern and southwestern part of the Sea. The sea lilies, which anchor themselves to stones or hard substrates, stretch their long arms up in the water. The by-catch showed that there bodies gets fragmented in the contact with the fishing gear and indicates that sea lilies are severely vulnerable to bottom trawling. In the investigated area, covering the entire Barents Sea with 789 stations the sea lilies were only recorded at some few stations in central and eastern Barents Sea.

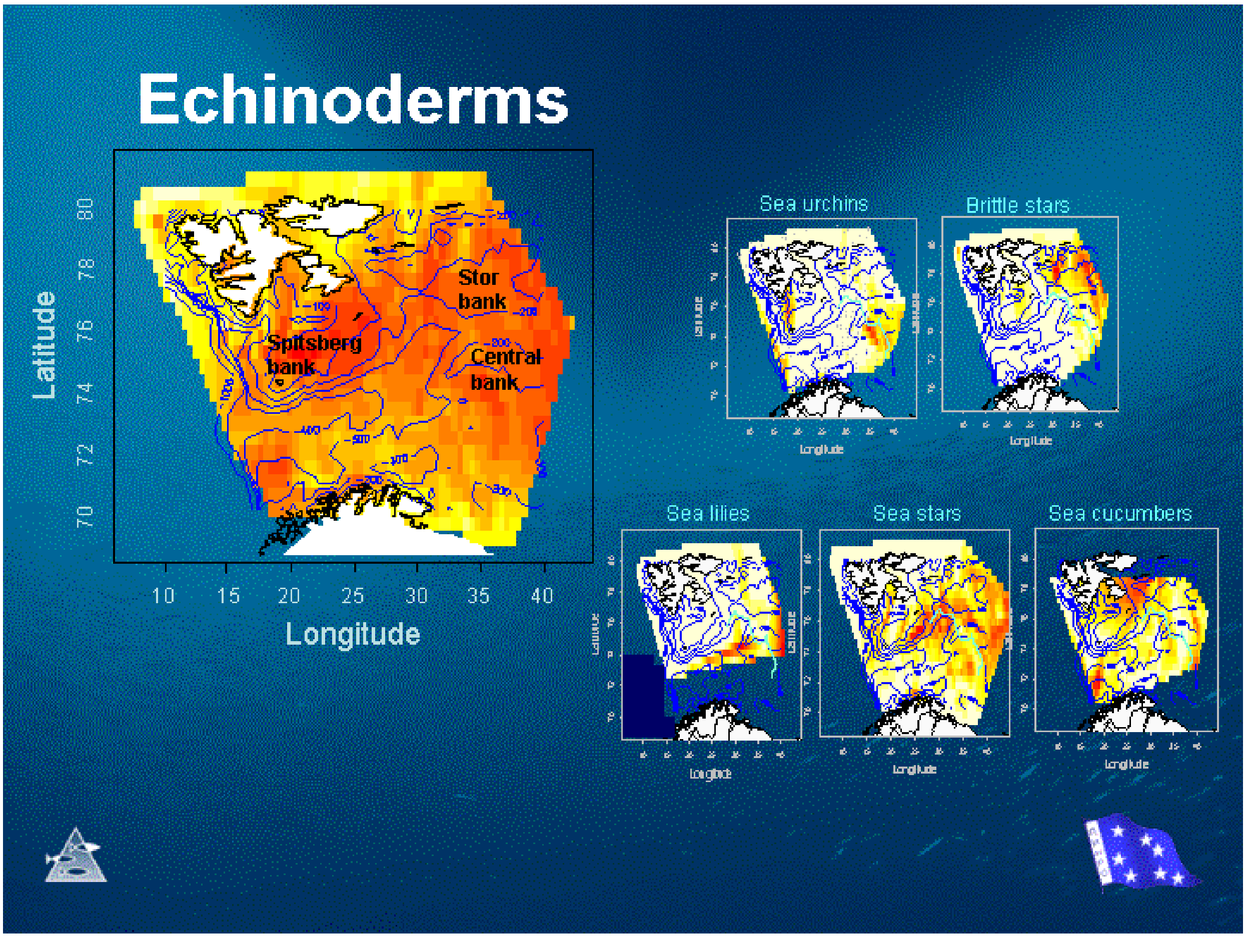


Figure 5.25. Echinoderm by-catch in kg, per 0.5 h trawling (~13.500m²), in August-September 2006. The weight data for the survey area were obtained by linear interpolation of the sampling stations estimates (log transformed). The light-blue line depicts the 3 °C isotherm at 100 m depth, indicating the northern distribution of Atlantic water. The dark-blue lines indicate depths in meters.

5.5.2 Expected situation

In order to predict the expected situation there is a need to identify the parts of the benthic ecosystem that are most susceptible to climatic change and to man's activities, which, among others, including physical disturbance (effect from bottom trawling and petroleum activity), introduced species (king crab). This requires both insight into the components of the ecosystem and the possible effects of the planed and ongoing activities in the region.

We should expect fluctuation in the biomass distribution of the benthic communities, because such fluctuations have been indicated before. In particular datasets, referred in Wassmann et al (2006), from 1924-1932 and 1968-1970 seems extensive enough to examine community change for the entire Barents Sea soft-bottom habitat. The auditors of this work conclude that biomass distribution clearly shows differences between the two periods. Although the relative locations of high biomass generally correspond between them, the overall magnitude of biomass was reduced by 60% in the late 1960´s compared to the late 1920´s. These studies also describes that regular sea temperature measurements conducted along the Kola Transect since the beginning of the 20th century indicate that the late 1960´s was a particularly cold period, compared to the 20th century average temperature. While one Russian work attributes the decrease in benthic biomass in the 1960´s to the cold water temperatures, another Russian work suggest a more complex relationship where fluctuation in biomass are more strongly related to direct anthropogenic disturbance, in form of intensity of bottom trawling, than to temperature fluctuations.

A large area north and northwest of the Finnmark coast and up to Svalbard might be affected by activities such as petroleum extraction and transport, bottom fishing (Figure 5.26), king crab invasion and influx of warm water species. Trawling for fish and shrimp concentrated to deep (> 200 m) sub sea valleys and canyons with soft and mixed substrata.

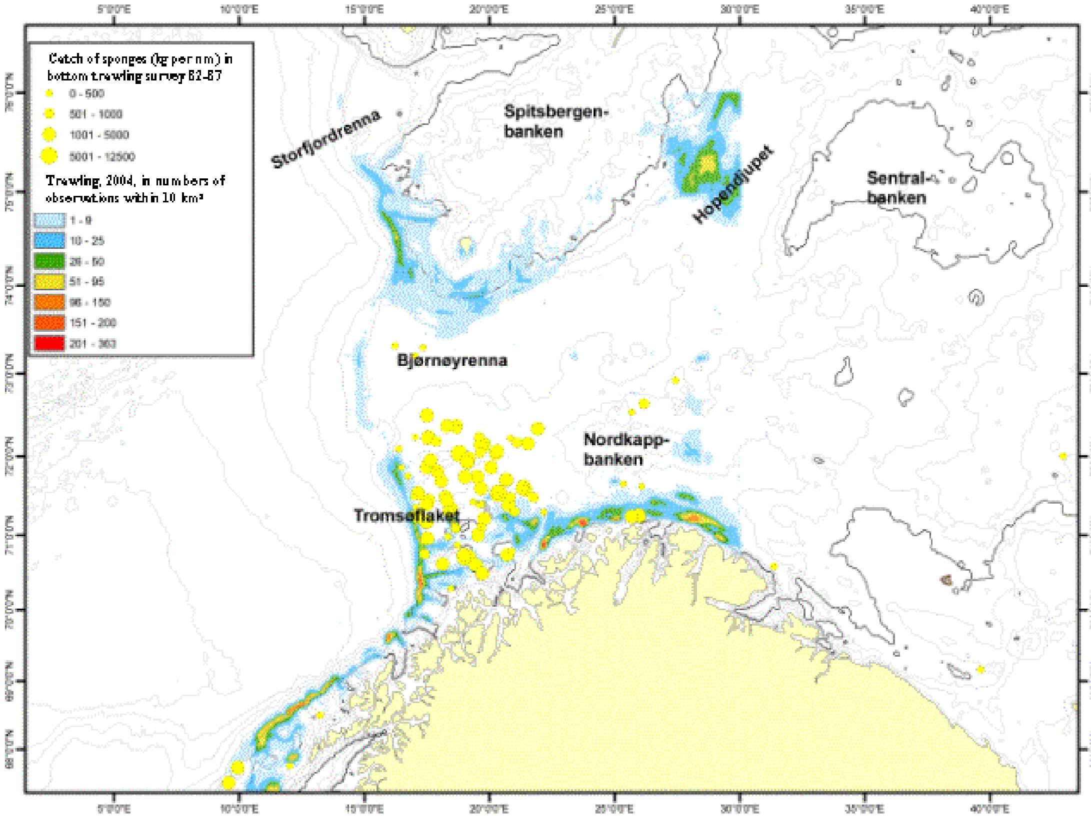


Figure 5.26. Trawling intensity based on satellite data, year 2004, from the Directorate of Fishery.

Oil-platforms will likely be situated on rocky bottoms outside the most active fishery areas. The seasonal migration of king crab subjects this animal to both soft offshore (< 400 m) and coastal near rocky - mixed bottoms.

5.6 Shellfish

5.6.1 Northern shrimp (*Pandalus borealis*)

Fishery

In the Barents Sea and off the Spitsbergen Archipelago, a fishery for shrimp has been conducted since the 1950s. The catches were maximal in the mid-1980s, in 1990-91 and 2000 (Figure 5.27). Russia had earlier a major presence in this fishery. During the recent decade annual yields have varied between 35 and 85 ktons. Norwegian vessels accounted for 70-90% of the total catches and vessels from Russia, Iceland, Greenland and the EU for the rest (Hvingel and Aschan, 2006).

Stock status

Russian and Norwegian survey vessels conduct major research effort to monitor this resource, and the results from these investigations form the basis for the assessment of stock status. Since the 1970s, the estimated median biomass-ratio has been above its MSY-level reaching a maximum in the mid 1980s. Since 2004 indices of stock size have increased. In 2006 the total stock of the Northern shrimp in the Barents Sea was estimated to be around 400.000 tonnes.

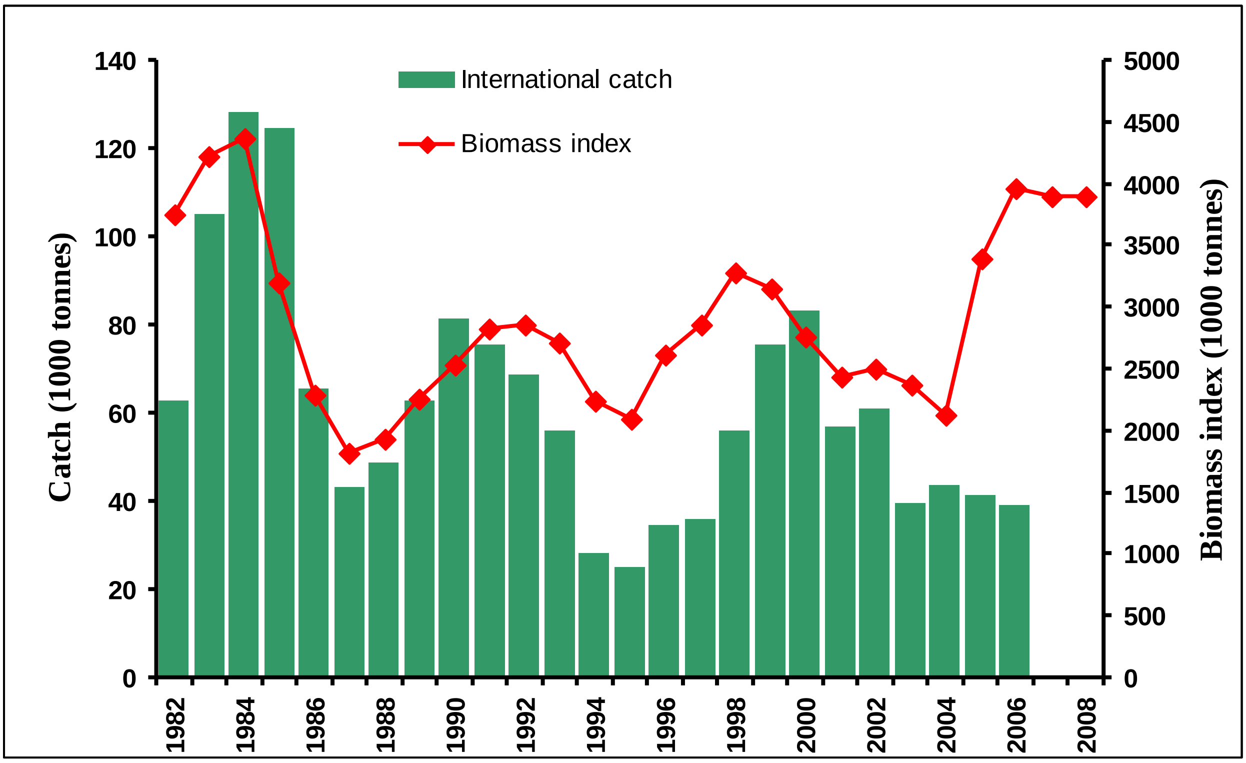


Figure 5.27. Long-term dynamics and forecast of the Northern shrimp commercial stock status and fishery in the Barents Sea and in the Spitsbergen area in 1982-2008.

5.6.2 Red king crab (*Paralithodes camtschaticus*)

Management of the red king crab in the Barents Sea was a joint management until 2006 when the two parties decided to carry out separate management in the two different economical zones.

In Russian waters of the Barents Sea, the maximal values of total and fishery abundance of red king crab were estimated in 2003 (Figure 5.28). Since 2004 a reduction in the adult population caused by low recruitment and high natural and fishing mortality, was observed. In 2006, the total and legal male abundance of the crab stock continued to decrease. According to the data from Russian summer-autumn survey, in 2006, the legal male stock amounted to 6.6 x 10^6 ind., which was two times lower than in 2003. The observed decrease was caused by low recruitment even in 2005 (Figure 5.28). Since 2005, the abundance of pre-recruits grew that might lead to the slight increase in the crab commercial stock in 2007-2008. For 2006 the indexes for the total stock in NEZ is constituted of 5 estimates, one for each area surveyed. In Varangerfjorden the estimate for 2005 is 2.30 million, 650 000 for the area Østhavet, 984 000 for Tanafjorden, 294 000 in Laksefjorden and 118 000 in Porsangerfjorden.

The estimate of legal males for Varangerfjorden 421 000 crabs, the new estimate for Østhavet is 258 000 crabs, for Tanafjorden 133 000 crabs and in Laksefjorden the estimate was 122 000 crabs in 2006. The first year sample of Porsangerfjorden gave an estimate of 86 000 legal males.

The number in Varangerfjorden is significantly lower this year compared to 2005, while there is a small increase in Tanafjorden. Estimates for Østhavet were probably to low in 2005 compared to the estimates for 2006 with an increase of 159 000 individuals. In Laksefjorden there is a small increase in index compared to 2005.

Density of crabs is still several times higher in Varangerfjord than in areas further west along the coast of eastern Finnmark. The crab also seems to spread mainly westwards in near coast areas and less offshore.

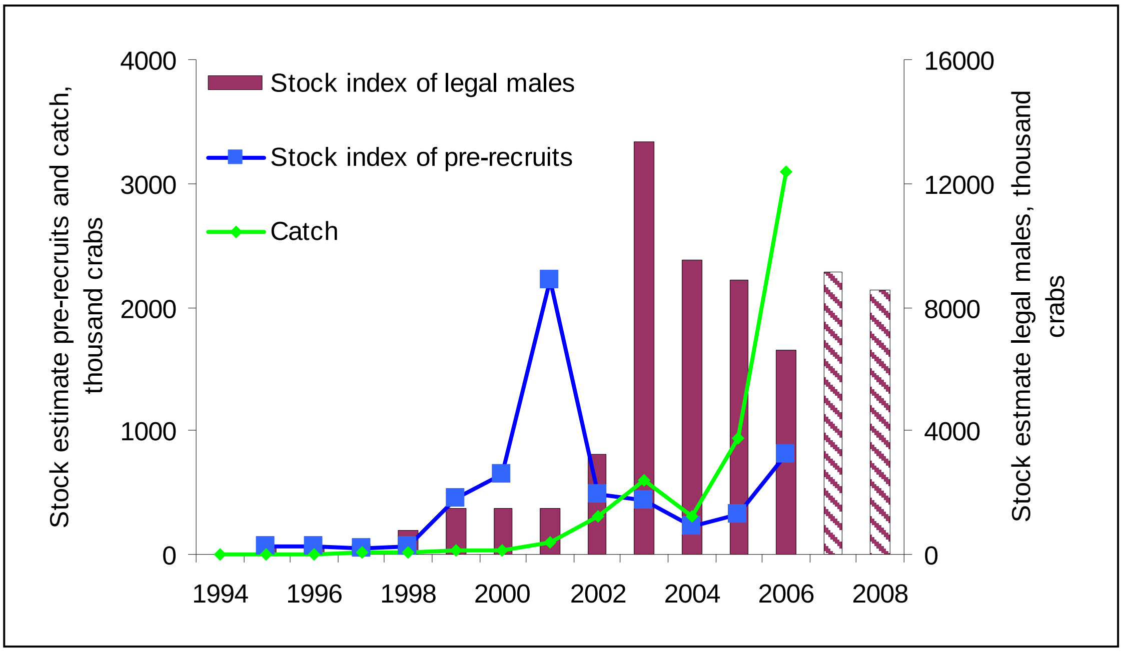


Figure 5.28. Dynamics of commercial stock, prerecruit abundance and the catch of the red king crab in Russian waters of the Barents Sea.

In 2006, the distribution of red king crab was characterized by dense concentrations (500-1000 ind./km^2 and more) in the eastern part of the Russian waters (Figure 5.29), where about 84% of the total catch was taken. The Russian catches of the red king crab in 2006 was estimated to 3 x 10^6 ind. (Figure 5.28).

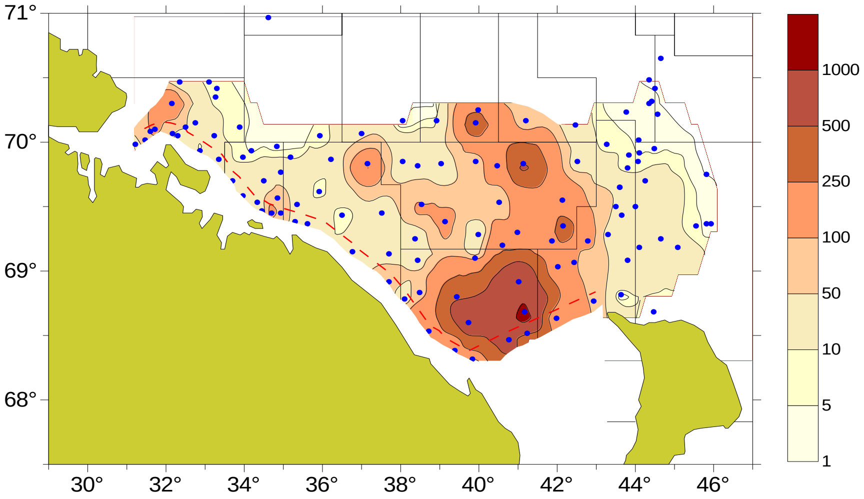


Figure 5.29. Distribution of red king crab total abundance in Russian waters of the Barents Sea in August-September 2006 according to the data from research trawl survey.

At present, the fishery of the red king crab in Russian waters is regulated by the following measures:

- fishery of the red king crab is based on getting a license;
- catch, acceptance, loading, processing and storage of the red king crab females as well as of males with 15 cm width of carapace are banned;
- fishing of crab is only permitted by traps with inner mesh size of not less than 70 mm;
- fishery and other kinds of utilization of the red king crab in the period of reproduction and moulting from 1 March to 31 August, as well as the harvesting at the depths of less than 100 m are forbidden.

5.6.3 Iceland scallop (*Chlamys islandica*)

Regular investigations of the Iceland scallop fishery resources in the Barents Sea were initiated by Russian scientists in 1987 and through scallop harvesting - in 1990.

The state of the scallop fishable stock in the Barents Sea in the period 1990- 2006 underwent significant changes. In 1990- 2006 the stock size in the Russian waters exceeded 500.000 tonnes, other years approaching 770.000 tonnes. Most part of the Iceland scallop fishable stock was found in the area of Svyatoy Nos Cape (Svyatoy Nos scallop settlement) where the basic fishery was concentrated.

In 2001 the degradation of the scallop population in the Svyatoy Nos settlement was observed which led to almost doubled decrease in the fishable stock. The most liable causes of the decrease in the scallop population in this area were: mollusks fungus disease, poor recruitment to the fishable stock, and a direct and indirect and fishing.

The scallop catches from 2001 to 2004 decreased considerably. The minimal catch rates observed in 2002. In the following years the catch slightly increased.

In 2005- 2006 the decrease in disease rate and an increased recruitment to the fishable stock was observed. Since 2005 a tendency for a growth in the fishable stock has been observed.

In 2006, the scallop fishable stock in the basic fishery beds in the Russian Economic Zone of the Barents Sea was estimated to 376.000 tonnes. The scallop catches amounted to 900 tonnes and consisted of scallops from 70 to 115 mm (mode – 85-90 mm). Juveniles with a shell height less than 80 mm amounted to 52.8% of the total scallop number. The average scallop size was 65.8 mm. Recruits made up nearly half of the fishable stock.

5.7 Fish

By B. Bogstad, A. Aglen, A. V. Dolgov, K. V. Drevetnyak, H. Gjøsæter, E. Johannesen, S. Mehl, Å. Høines and O. V. Smirnov

5.7.1 Cod (*Gadus morhua*)

Based on the most recent estimates of spawning stock biomass (SSB, Figure 5.30), ICES classifies the stock as having full reproductive capacity. Based on the most recent estimates of fishing mortality, the stock is exploited with a much higher fishing mortality than that intended under the management plan. The SSB has been above B_{pa} since 2002. Surveys indicate that recent year classes are at or below average.

Fishing mortality was reduced significantly from 1999 to 2003 but has since then increased to about 0.7 in 2004-2006, close to F_{lim} (0.74). This level of fishing mortality is above the level that would lead to high long-term yields (indicated to be in the F range 0.25-0.5). This indicates that long-term yield will increase at fishing mortalities well below the historic values. Fishing at such a lower mortality would lead to higher SSB and therefore lower the risk of observing the stock outside precautionary limits.

There are concerns about under-reporting of catches in recent years. Estimates for 2002-2006 indicate on average 27% in addition to official catches due to unreported landings. 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.

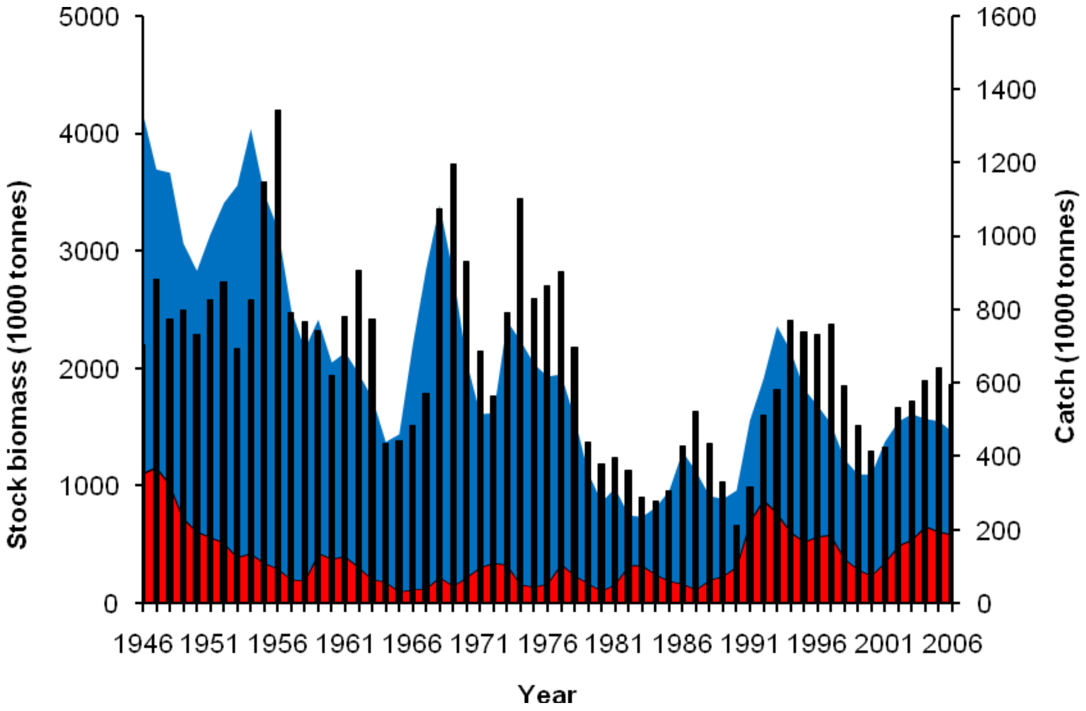


Figure 5.30. Northeast Arctic cod, development of spawning stock biomass (red area), total stock biomass (age 3 and older, blue area) and landings (columns).

5.7.2 Haddock (*Melanogrammus aeglefinus*)

Based on the most recent estimates of SSB (Figure 5.31), ICES classifies the stock as having full reproductive capacity. The assessment is uncertain due to data revision undertaken in 2006, incomplete coverage of the distribution area in the last year and conflicting signals comparing estimates from XSA and indices from surveys. The fishing mortality increased in 2004-2006 to values above F_{pa} in the last two years. Nevertheless, the assessment indicates that the spawning stock have stabilized at a high level, considerably higher than the long-term mean. Very strong year classes of 2004-2006 are expected to recruit the fishable stock in 2007-2009, which has potential to grow considerably.

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.

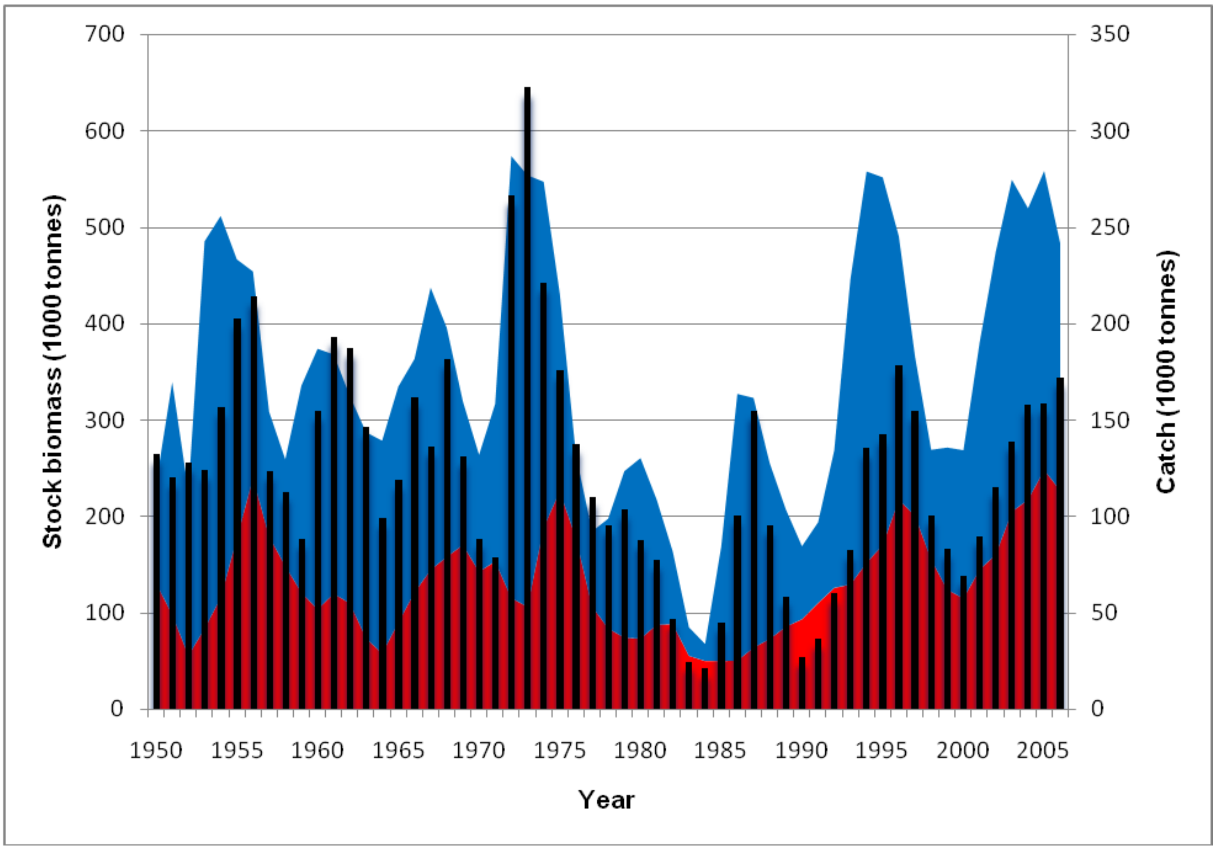


Figure 5.31. Northeast Arctic haddock, development of spawning stock biomass (red area), total stock biomass (age 3 and older, blue area) and landings (columns).

5.7.3 Redfish (*Sebastus mentella* and *Sebastus marinus*)

Deep-Sea Redfish (Sebastus mentella)

Recruitment failure has been observed in surveys (Figure 5.32) for more than a decade. However, signs of improved recruitment of 0-group and juveniles 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 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. This stock will not be able to support a directed fishery for several more years at least. Rather, it will be necessary to prevent the stock from declining further and to maintain measures to protect this stock from bycatch in other fisheries.

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 31 thousand tonnes, the highest level since 1991. There are uncertainties in the stock identity of the *S. mentella* caught in international waters of the Norwegian Sea, but it is most likely to belong to the same stock as the *S. mentella* found along the Norwegian coast and in the Barents Sea. In any case, the fishery for *S. mentella* in international waters of the Norwegian Sea is not in accordance with the precautionary approach.

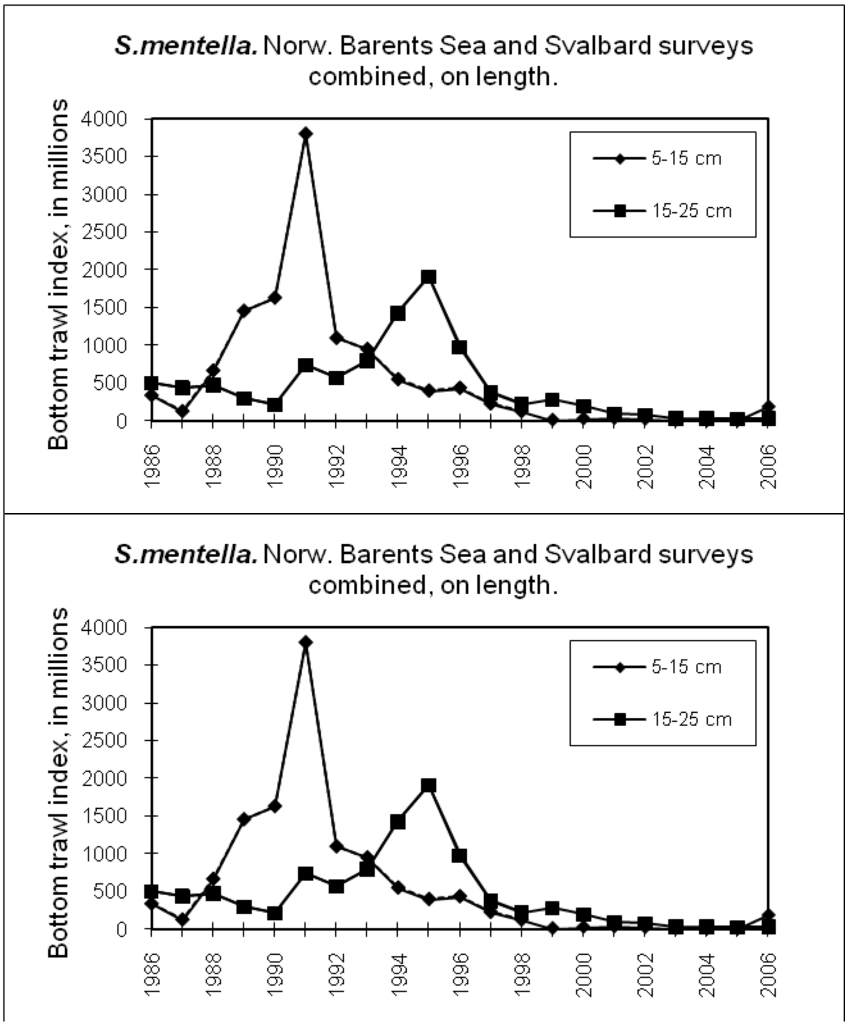


Figure 5.32. Sebastes mentella. Abundance indices (by length) when combining the Norwegian bottom trawl surveys 1986-2006 in the Barents Sea (winter) and at Spitsbergen (summer/fall).Upper panel: Small fish, lower panel: Large fish.

Golden Redfish (Sebastus marinus)

In the absence of defined reference points the state of the stock cannot be fully evaluated. Surveys (Figure 5.33) 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.

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 Spitsbergen 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 7,500 t for the last 4 years, a level which seems to cause a continued decline of this stock.

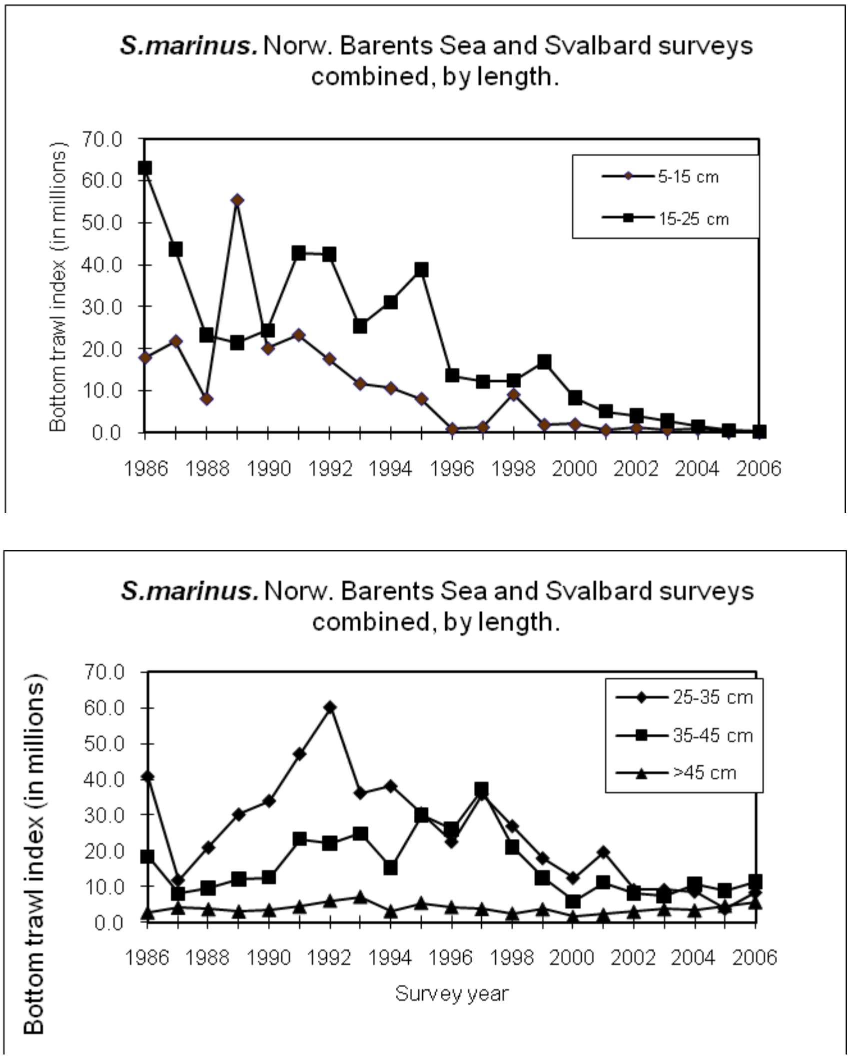


Figure 5.33. Sebastes marinus. Abundance indices (by length) when combining the Norwegian bottom trawl surveys 1986-2006 in the Barents Sea (winter) and at Spitsbergen (summer/fall).Upper panel: Small fish, lower panel: Large fish.

5.7.4 Greenland halibut (*Reinhardtius hippoglossoides*)

In the absence of defined reference points the status of the stock cannot be fully evaluated. The tentative assessment done by ICES indicates that SSB has been low since the late 1980s, but a slight increase is indicated in recent years. There are indications of a decreasing trend in fishing mortality since the 1990s. Recruitment has been stable at a low level since the 1980s. The stock has remained at a relatively low size in the last 25 years at catch levels of 15 000-25 000 t. In order to increase the SSB, catches should be kept well below that range.

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 are that the stock has increased in recent years both in a tentative assessment and in fishery independent surveys. During this period, catches in that fishery have been around 13 000 t (Figure 5.34). 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.

The assessment is uncertain 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.

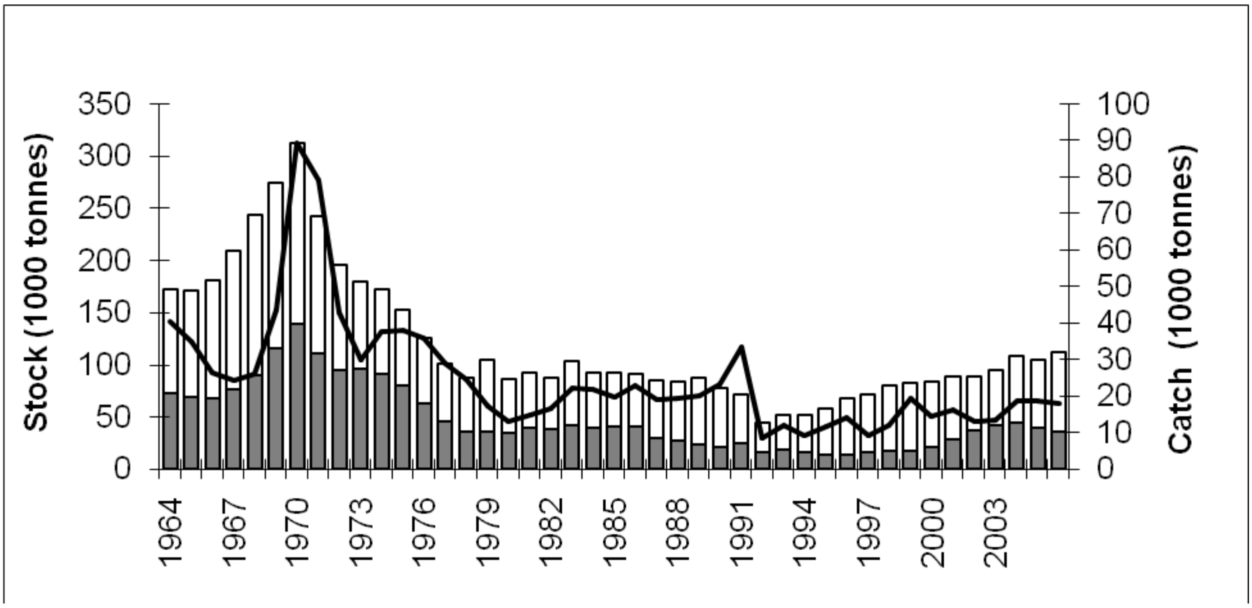


Figure 5.34. Northeast Arctic Greenland halibut; landings (black line), spawning stock (grey columns) and total stock (white columns) 1964-2006.

5.7.5 Capelin (*Mallotus villosus*)

The spawning stock (Figure 5.35) of capelin in 2007 is predicted from the acoustic survey in September 2006 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 any catch level in 2007, the probability of having an SSB below 200,000 t is above 50 %. Only catches of mature fish have been considered.

Based on the most recent estimates of SSB and recruitment ICES classifies the stock as having reduced reproductive capacity. The maturing component in autumn 2006 was estimated to be 0.44 mill tonnes. SSB 1st April 2007 is predicted to be at 0.19 mill tonnes, which is just below B_{lim}. The spawning stock in 2007 will consist of fish from the 2003 and 2004 year classes, but the 2004 year class will dominate. The survey estimate at age 1 of the 2005 year class is below the long-term average. Observations during the international 0-group survey in August-September 2006 indicated that the size of the 2006 year class is above the long term mean.

The estimated annual consumption of capelin by cod has varied between 0.2 and 3.0 million t over the period 1984-2006. 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 onwards.

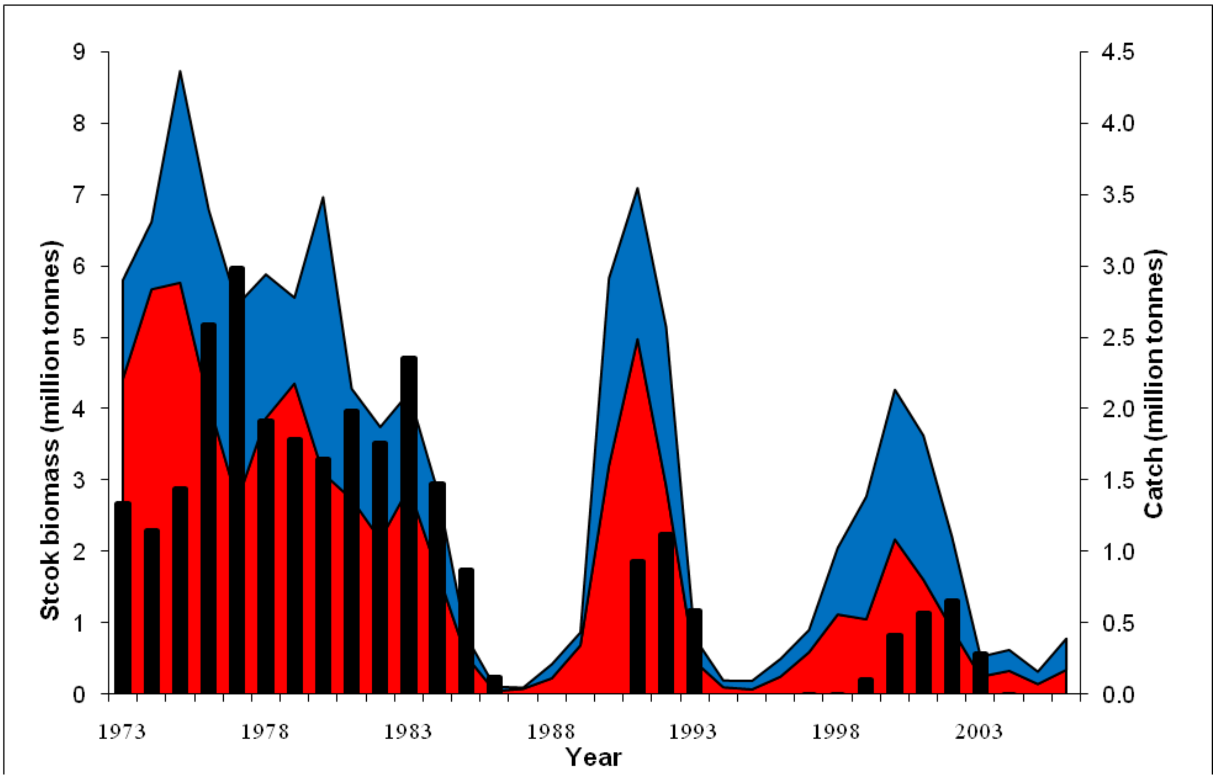


Figure 5.35. Barents Sea capelin. Total stock (blue area) and maturing component (red area) during autumn, and total landings (columns), 1973–2006.

5.7.6 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 and 1999 year classes dominate the current spawning stock which is estimated to 10.3 million t in 2006. The 2002 year class is estimated to be strong and has now recruited to the fishery. The 2004 year class is also strong, but most of this year class will probably leave the Barents Sea in 2007. Preliminary indications show that the 2006 year class may also be abundant, although considerably weaker than the 2004 year class. Therefore the abundance of herring in the Barents Sea is believed to be at an intermediate level in 2007.

This stock has shown a large dependency on the occasional appearance of very strong year classes (Figure 5.36). 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.

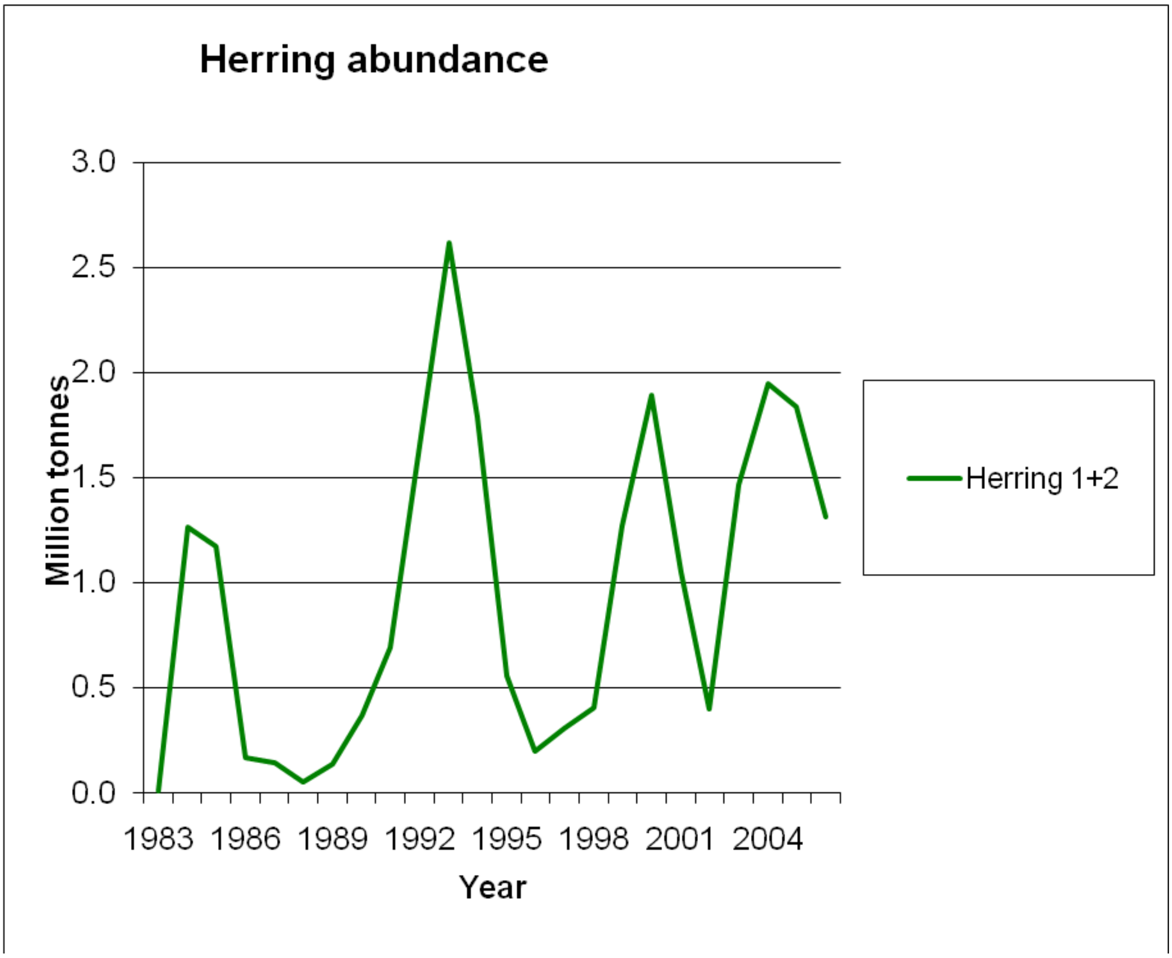


Figure 5.36.Abundance of age 1 and 2 herring, calculated by VPA, which is a good indication of the abundance of young herring in the Barents Sea.

5.7.7 Polar cod (*Boreogadus saida*)

The polar cod stock is presently at a high level (Figure 5.37). 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 tonnes. In 2006, the stock size was measured to about 1.9 million tonnes.

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

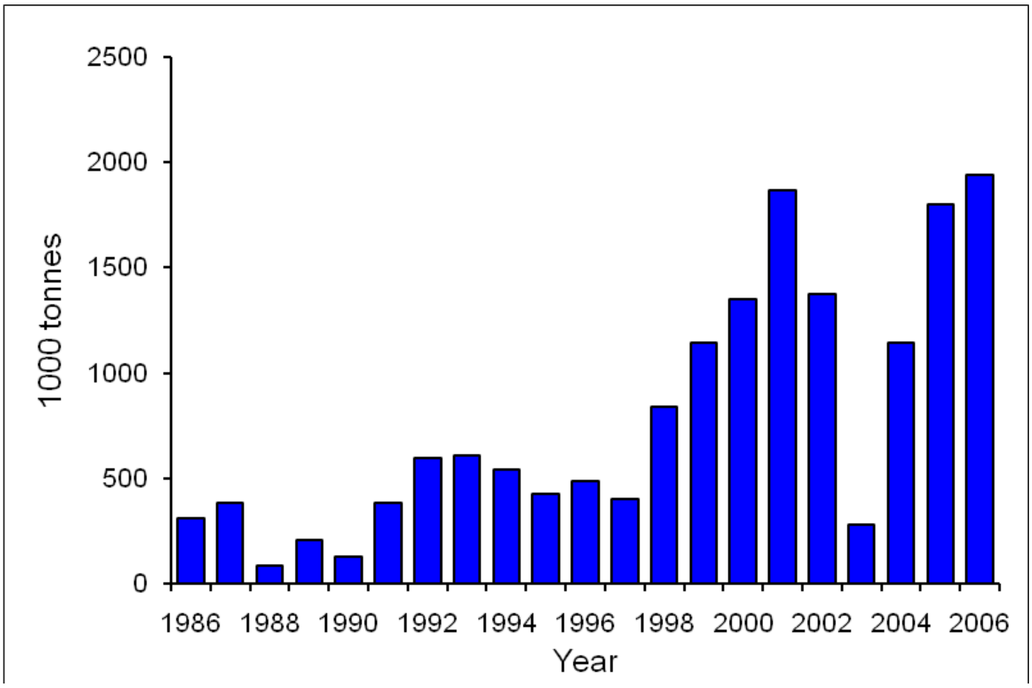


Figure 5.37. Polar cod. Stock size estimates obtained by acoustics, 1986–2006.

5.7.8 Blue whiting (*Micromesisius 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 in 2004-2006. Although the estimates of SSB and fishing mortality are uncertain, the estimate of SSB appears to be well above B_{pa}. The estimated fishing mortality is well above F_{pa}, and is estimated to have been at F_{lim} in 2004. Recruitment in the last decade appears to be at a much higher level than earlier, but seems to be decreasing in the last couple of years. Total landings in 2005 were 2.0 mill. tonnes, which is about 15% lower than in 2004. Recent large landings are supported by the current high recruitments, and are much higher than in earlier years. Blue whiting is not fished in the Barents Sea.

The high abundance of blue whiting in the Barents Sea (Figure 5.38) 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 as now, and never as far east and north in this area as in 2004-2006. In autumn 2006, the acoustic abundance of blue whiting was estimated to 0.7 million tonnes, which is lower than in 2004-2005.

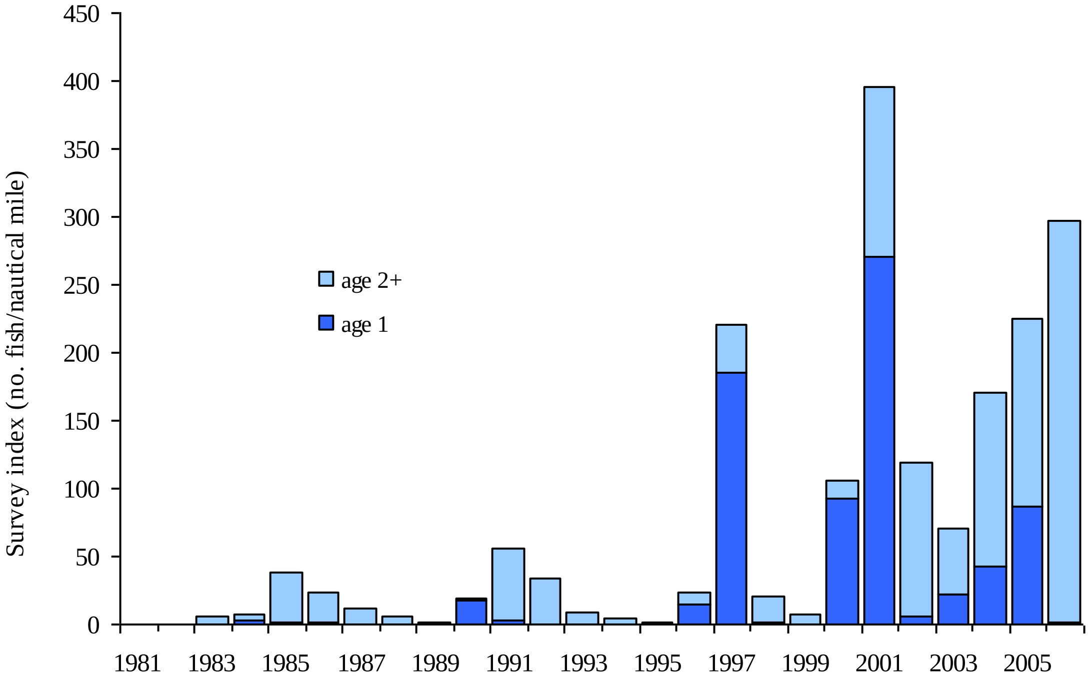


Figure 5.38. Blue Whiting. Abundance (catch in numbers per nautical mile) of blue whiting in the Barents Sea winter survey 1981-2006.

5.7.9 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 F_{pa}. The SSB (Figure 5.39) has since 1994 been well above B_{pa}. 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 ($F_{0.1}$ =0.14).

ICES has in 2007 evaluated a proposed Harvest Control Rule (HCR) and concluded that it is consistent with the precautionary approach under the conditions that the assessment uncertainty and error are not greater than those calculated from historic data. 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 F_{pa} = 0.35 and to keep the between year TAC change to within +/- 15%, unless SSB falls below B_{pa} 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 (F_{pa}), and ICES recommend using a lower value in the HCR. ICES recommend that the proposed and evaluated HCR plan be implemented. This implies a TAC of 247 000 t in 2008, or less if a lower target fishing mortality is chosen.

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.

There is a substantial migration of immature saithe to the North Sea from the Norwegian coast between 62ºN and 66ºN. In some years, there are also examples of mass migration from northern Norway to Iceland and, to a lesser extent, to the Faeroe Islands.

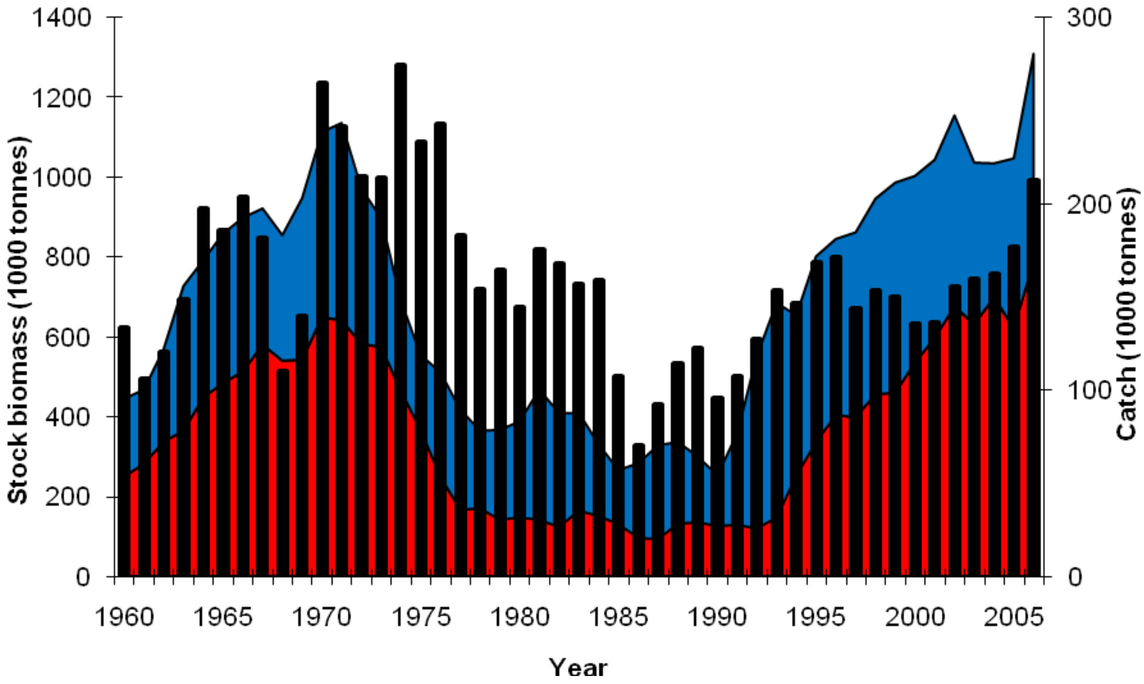


Figure 5.39. Northeast Arctic saithe, development of spawning stock biomass (red area), total stock biomass (age 3 and older, red and blue area) and landings (columns).

5.7.10 Other species

There is over 100 fish species regularly occurring in the Barents Sea. This is too many for regular monitoring of distribution and abundance. We therefore present trends for only a few other species; snake pipefish because it's conspicuous increase in the Barents Sea the last years, and the wolfish species, because of some recent work done on this species at IMR (Johannesen et al. 2007).

5.7.10.1 Wolffish (Anarhichas)

There are three wolffish species in the Barents Sea. Striped wolffish (*Anarhichas lupus*) has a wider, more southern distribution than spotted (*A. lupus*) and Northern wolffish (*A. denticulatus*), and extend south into the North Sea (ICES 2006). The biology of the three species differs. A conspicuous difference between Northern wolffish and the other species is that regularly only larger specimens of Northern wolffish are found in the Barents Sea (Figure

5.40). *A. minor* and *A. denticulatus* occur as by-catch in cod and haddock trawl fisheries, *A. minor* is also by-catch species in long line fisheries, whereas *A. denticulatus* is targeted by the Russian long-line fishery. The average number of *A. denticulatus* caught in survey hauls (excluding zero catches) on the winter survey has declined significantly since 1993 (p=0.004, whereas the two other species has not significantly declined (Table 5.4).

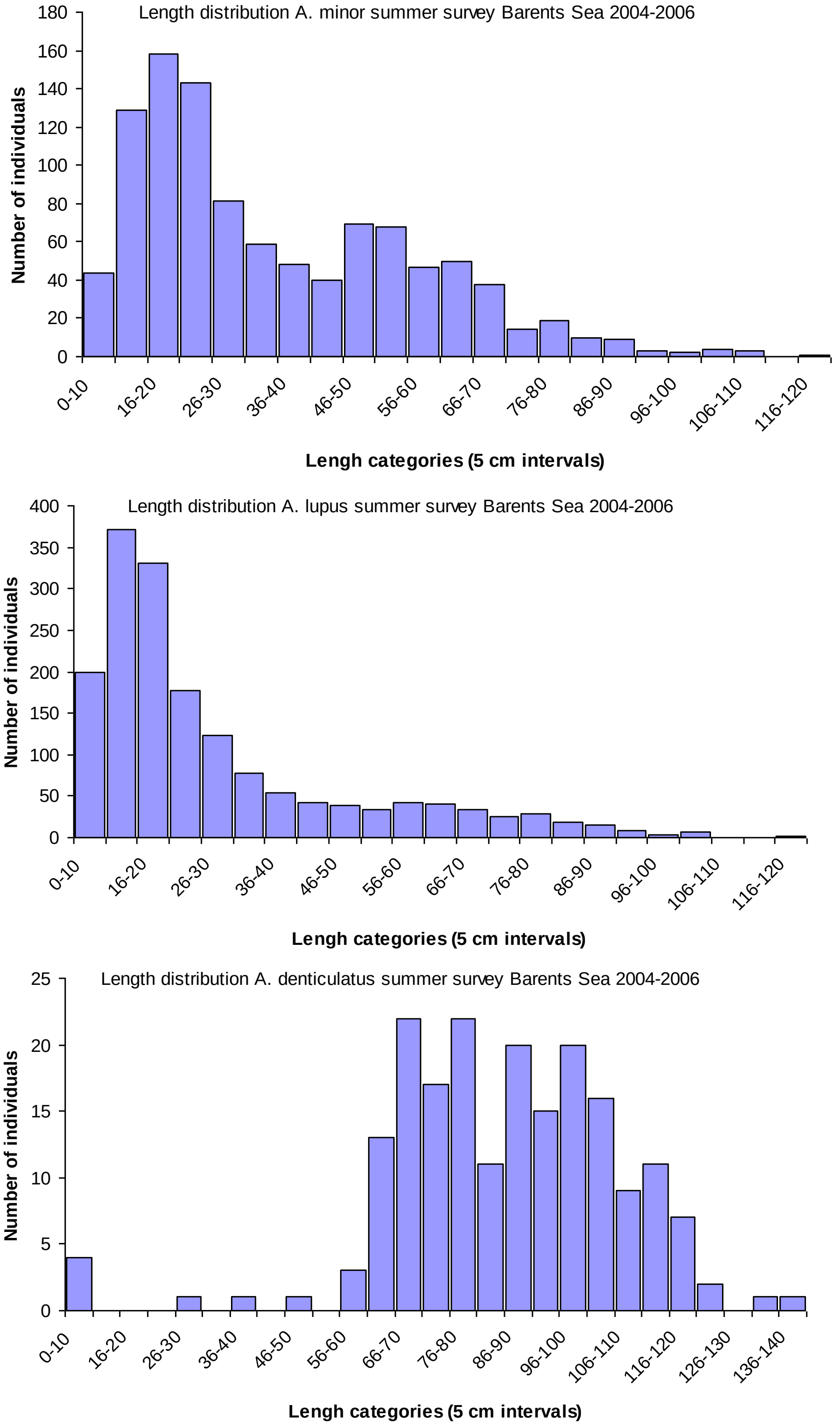


Figure 5.40. Length distribution of the three wolffish species in the Barents Sea ecosystem survey in summer/autumn 2004-2006.

Table 5.4. Local abundance (number per haul, excluding zero catches) of wolffish in the Barents Sea, calculated from the winter survey data (February 1993-1996 and 1999-2006).

	A. denticulatus	*A. minor*	*A. lupus*
1993	2.21	3.05	4.66
1994	2.58	3.56	4.77
1995	2.44	2.27	4.81
1996	2.63	2.84	7.08
1999	1.98	3.49	5.36
2000	2.34	2.59	4.02
2001	1.86	2.30	5.43
2002	1.75	2.73	7.15
2003	1.64	2.52	7.05
2004	2.43	2.72	5.37
2005	1.39	2.87	5.75
2006	1.22	2.29	7.57

5.7.10.2 Snake pipefish (Entelurus aequoreus)

There has been a dramatic increase in the abundance and northward distribution (Figure 5.41 and Figure 5.42) of Snake pipefish (*Entelurus aequoreus*) since 2003, with its area of distribution now including the Atlantic water along the west coast of Spitsbergen and in the Barents Sea (Harris *et al.* 2006, Rusyaev et al. in press). The increase in abundance can be attributed to the increase in temperature of the Atlantic water and in creased abundance of this species in southern areas of the North Atlantic (Kirby et al. 2006). The ecological significance of this new element in the food chain is not clear. It seems to be caught by a wide range of seabird species, but seems to be associated with poor breeding success in UK breeding colonies (Harris *et al.* 2006). A few specimens of this species were also found in cod stomachs in the Barents Sea in 2006.

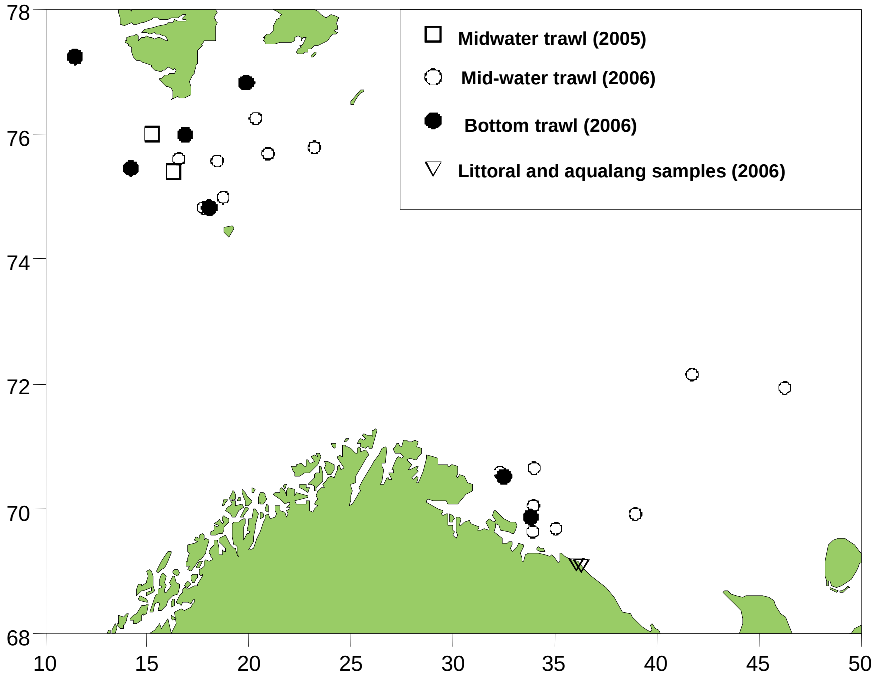


Figure 5.41. Occurrence of snake pipefish based on Russian data (from Rusyaev et al., in press)

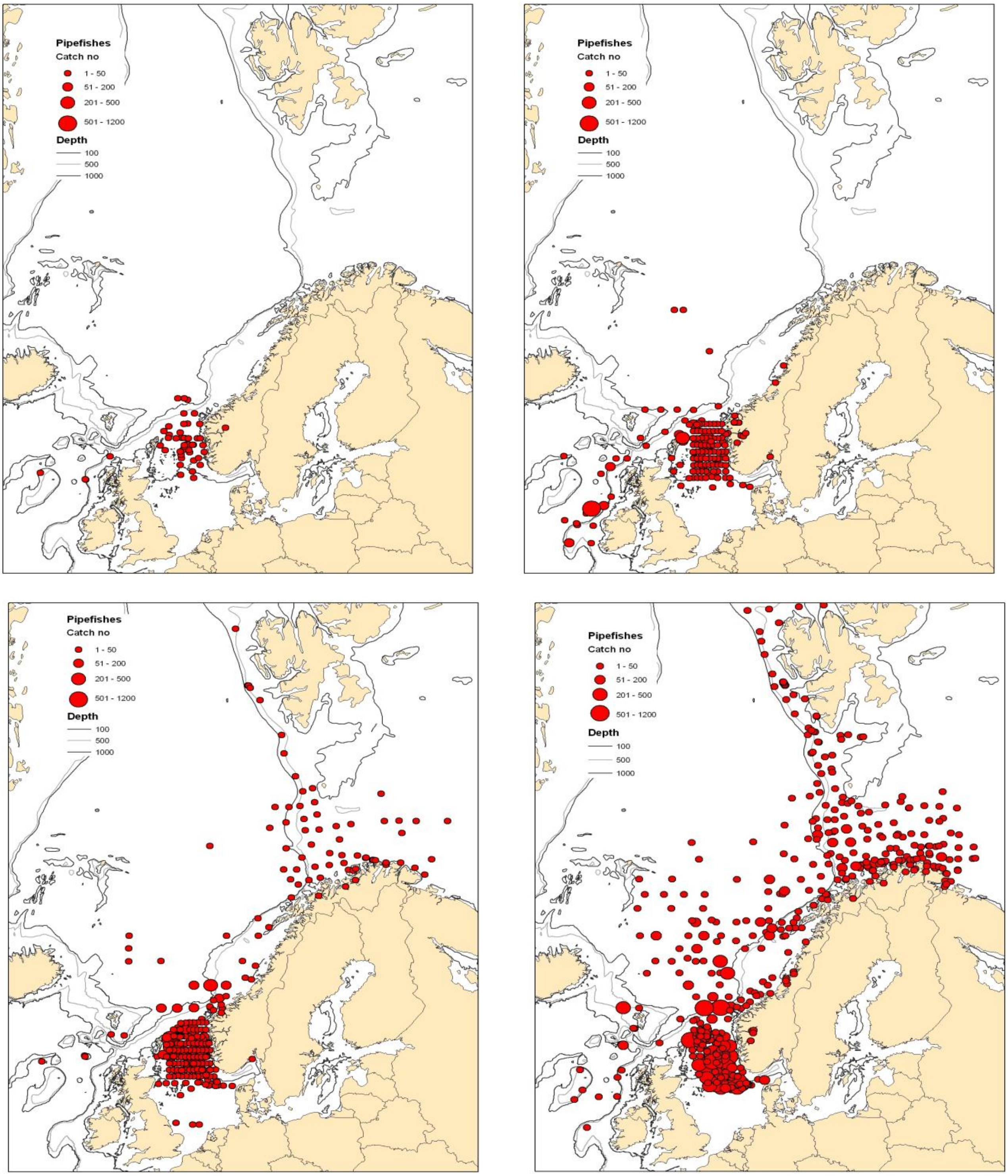


Figure 5.42. Distribution of the snake pipefish Entelurus aequoreus caught by Norwegian survey vessels in northern European seas 2003 - 2006. Catch per unit effort (numbers per 30 minutes). Figures from Harris et al. (2003-2005) and IMR, Bergen (2006).

5.8 Marine mammals and seabirds

By V. B. Zabavnikov, M. Mauritzen, S. V. Ziryanov and N. Øien

5.8.1 Current situation

Information on the current situation of marine mammals and seabirds in the Barents Sea is mainly collected by dedicated observers on board research vessels during the ecosystem cruise in August – September and by the collection of incidental observations from e.g. coastguard and research vessels throughout the year. The aims of these investigations are to study distribution patterns of the main species of marine mammals and seabirds in the Barents Sea, and to determine the mechanisms underlying these distributions, such as prey selection, prey distribution and habitat use. As marine mammals and seabirds are long-lived species, short-term fluctuations within the Barents Sea system are more likely to influence the distribution of these top predators and their interactions with prey species, rather than affecting their abundances.

5.8.1.1 Marine mammals

During the ecosystem survey in the Barents Sea in 2006, 455 observations of 1,766 marine mammal individuals comprising 18 identified species were recorded from the research vessels “Johan Hjort”, “G.O. Sars”, “Jan Mayen”, “F. Nansen” and “Smolensk”. Fewer observations were recorded this year compared to previous years as no aerial survey was conducted in 2006. Additionally, ca 900 incidental observations of marine mammals were obtained during the summer 2007.

The most abundant cetacean in terms of individuals was the white-beaked dolphin, which was observed over large parts of the Barents Sea (Figure 5.43). The white beaked dolphins prey on pelagic fish such as capelin, herring and possibly blue whiting. Hence their wide distributions are determined by the wide distributions of pelagic fish species in the Barents Sea. It’s sibling species, the white-sided dolphin, which is a more oceanic species, was also recorded with a few observations in the south-eastern Barents Sea. Dolphin species usually occur in groups of 5-15 individuals and often show ship-seeking behaviour. In the south-eastern Barents Sea a couple of observations were made of common and striped dolphins, which are both thought to be associated with warmer water and represent occasional occurrences in northern waters due to influx of warm water masses.

Northern bottlenose whales was as in previous years observed in the western Barents Sea along the continental slope (Figure 5.44). It was noted that whales from this aggregation followed fishing vessels and fed on fish from both trawls and long-lines during fishing operations. Aggregations of the Northern bottlenose whales were observed in the southeastern Barents Sea also this year, within feeding areas often used by other cetaceans and harp seals (Figure 5.44). Apart from pelagic fish, the squid *Todarodes sagittatus* may also inhabit this area, which may be a preferred prey for the bottlenose whale. More observations of bottlenose whales were registered in 2006 than in previous years, and with the eastern occurrences of this species the geographic distribution of this species have expanded considerably. The causes of this expansion remain unknown.

Of the baleen whales, minke, fin and humpback whales were most numerous. Minke whales were observed in most parts of the Barents Sea (Figure 5.45). Minke whales are mainly solitary animals. However, a large feeding aggregation of more than 200 individuals was observed on the Kanin Bank and Murmansk Shallows, and an aggregation of unknown number was observed off Novaya Zemlya. These aggregations were probably associated with abundant herring and polar cod. Furthermore, in August a smaller group of minke whales (50-60 individuals) occurred in the area off the Murmansk coast, between Teriberka and Dvorovaya where they fed on sand lance. The aggregations of minke whales in northern and western areas typically occurred were capelin and herring was available.

Humpback whales were observed in aggregations in northwestern Barents Sea around the Bear Island and the Hopen trough (Figure 5.46). Their presence in this area seems mostly related to concentrations of capelin and possibly krill. In autumn aggregations were observed in northeastern Barents Sea, some humpback whales reached the Frantz Josef Land. These humpback whales preyed on large schools of capelin together with other species of marine mammals, most often jointly with white-beaked dolphins. Humpback whale aggregations were also observed along the west coast of Spitsbergen, predominantly outside Prins Karls Forland.

Fin whales generally inhabit the deeper areas along the continental slopes, west of Spitsbergen and in the Storfjorden trough. However, both in 2005 and 2006 fin whales were also observed in the central and northern Barents Sea (Figure 5.47), thus expanding the general distribution area. Fin whales are associated with both pelagic fish and 0-group fish, but the causes of this range expansion remain unknown. The sei whale is a deep-water species foraging on zooplankton. The species is, however, observed occasionally in the Barents Sea, and was also observed in 2006 along the shelf edge and in the south eastern Barents Sea. The bowhead whals is a rare species in the north-east Atlantic and only a few observations have been recorded the last years around Spitsbergen and off Franz Josef Land. In 2006 one bowhead whale was observed in the south-eastern Barents Sea, and one in the central Barents Sea (Figure 5.47). Blue whales were observed west of Spitsbergen. This is now an area where blue whales seem to visit quite regularly. A few sperm whales were observed along the continental slope towards the Norwegian Sea. A group of white whales was observed in the southeastern Barents Sea.

The harbour porpoise is a coastal fish-eating species. In 2006, larger feeding aggregations in southern Barents Sea were recorded, and some of these aggregations were in open water north of the coastal regions (Figure 5.47). In the Barents Sea harbour porpoises occur in small groups, up to 10 animals, rarely forming large aggregations and shoals.

Harp seals and walruses were observed north of Spitsbergen in autumn, within their expected main distributional area at this time of the year. However, the number of harp seals recorded this year was much less than last year when very large groups were observed along the ice edge. In 2006, there were no airborne surveys at the breeding grounds in the White Sea to estimate harp seal pup production. However, based on airborne surveys in previous years and at sea surveys conducted in the White Sea in 2006 the number of pups was estimated to 110 thousand pups (SE=19000), which is 10% less than the estimated pup numbers in 2005. These numbers indicate that a reduction in pup production on the whelping grounds, which started in 2004, is continuing, although at a lower rate.

It is important to note that the observed distributions of marine mammals shown in Figure 5.43- Figure 5.47 are not effort corrected. Due to unfavourable weather and light conditions observers were only actively searching during parts of the survey time, which may yield biased distribution maps.

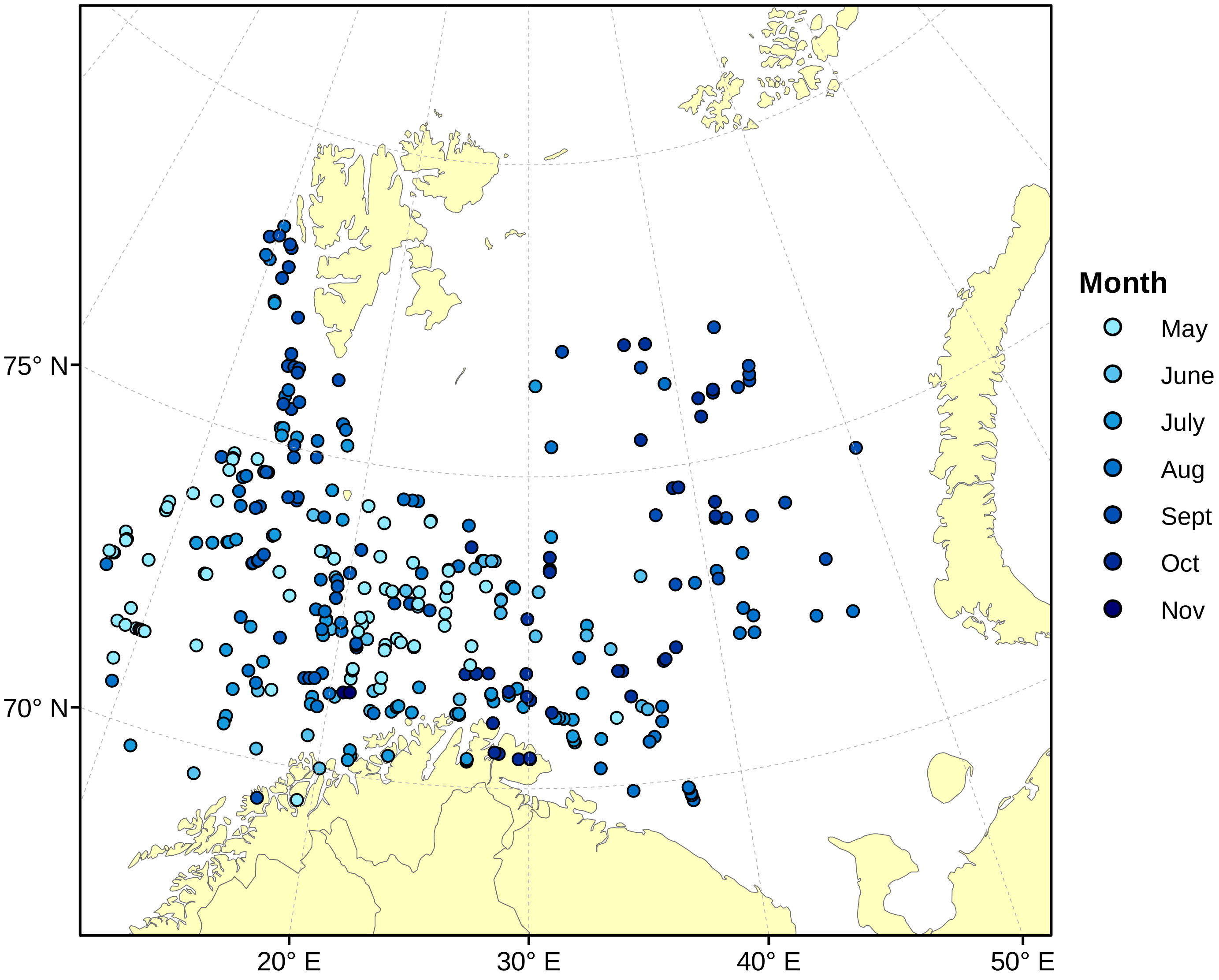


Figure 5.43. Observations of white-beaked dolphins in the Barents Sea summer and autumn 2006.

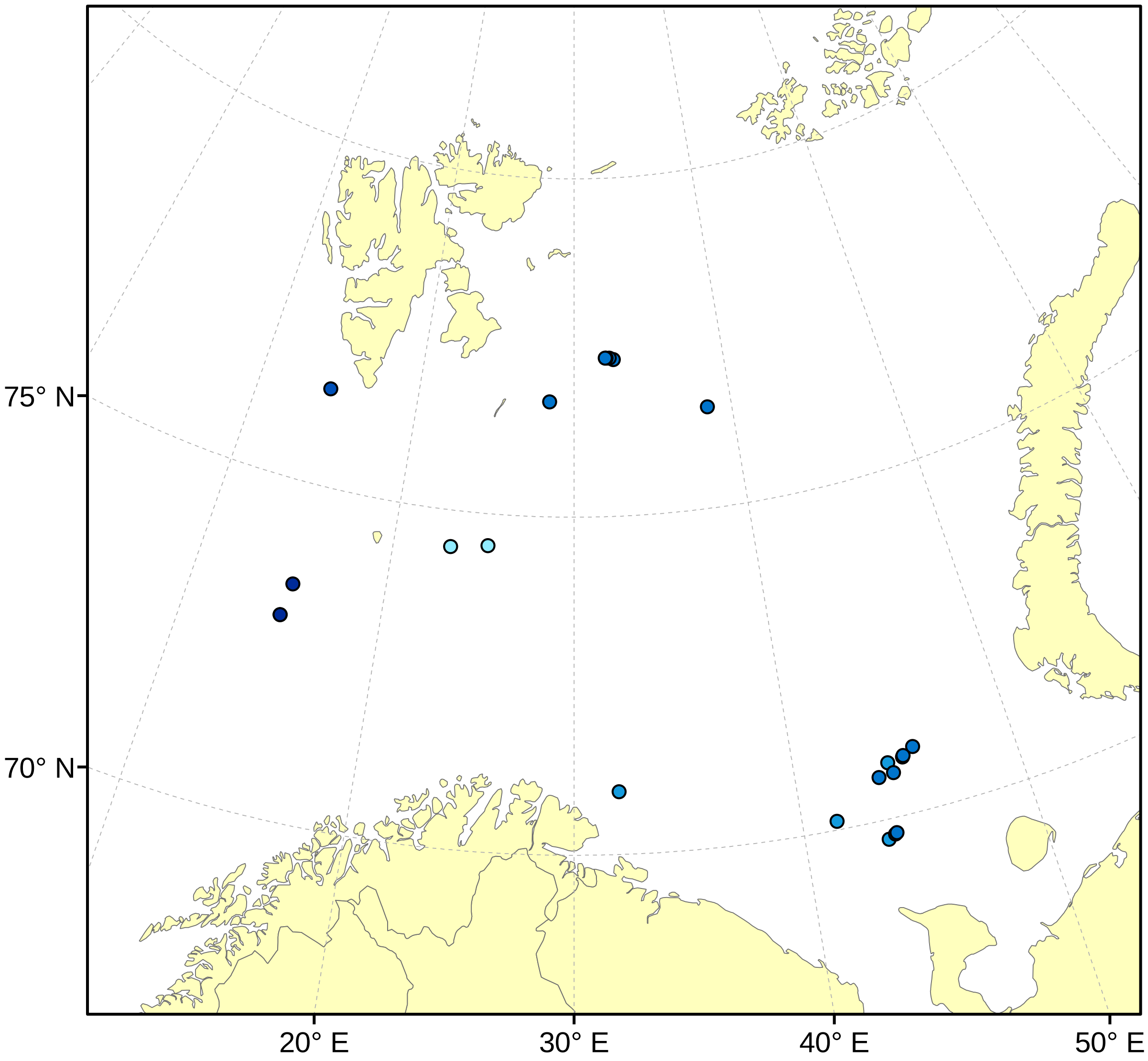


Figure 5.44. Observations of Northern bottlenose whales in the Barents Sea summer and autumn 2006. For colour codes, see legend in Figure 5.43.

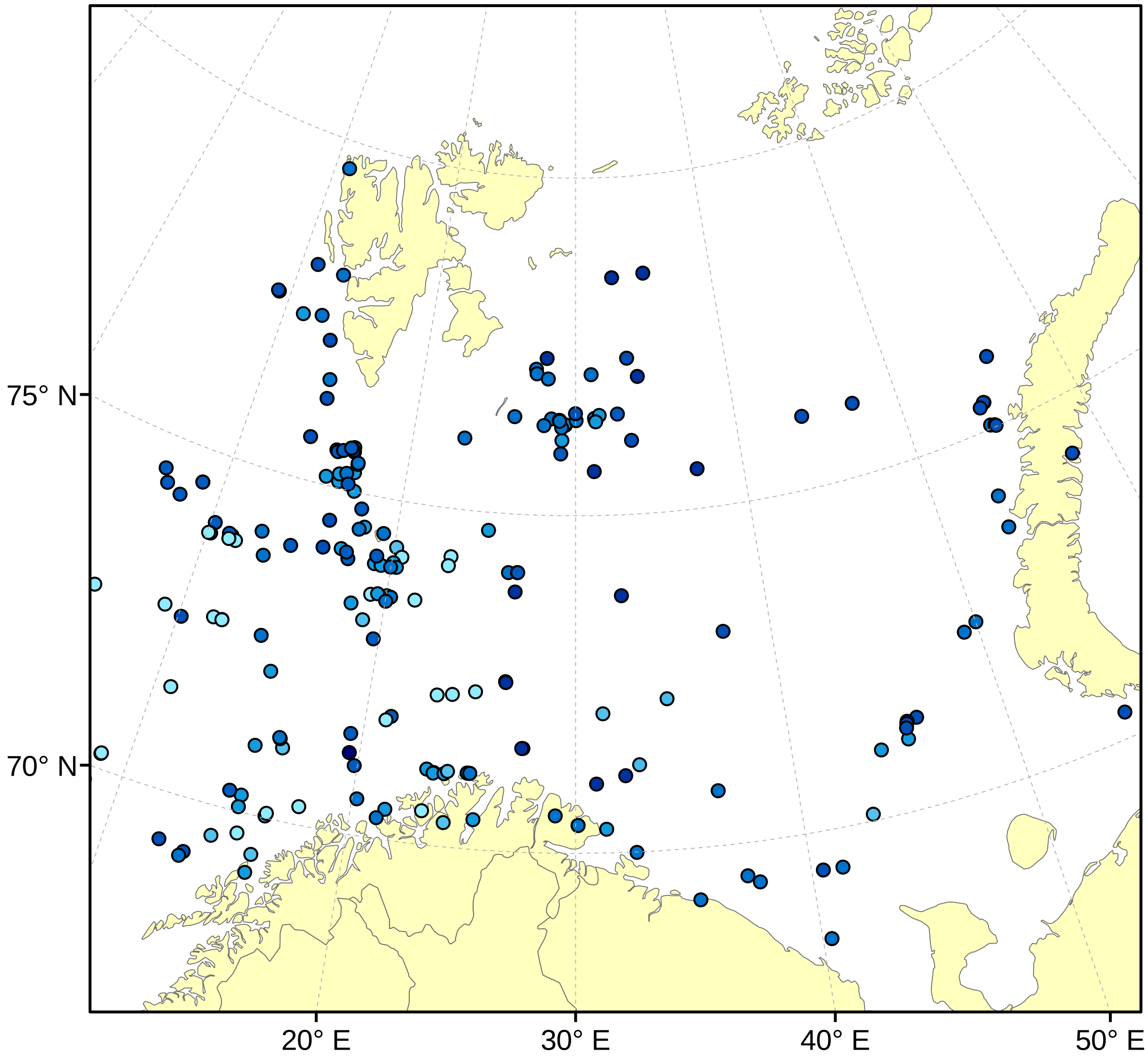


Figure 5.45. Observations of minke whales in the Barents Sea summer and autumn 2006. For colour codes, see legend Figure 5.43.

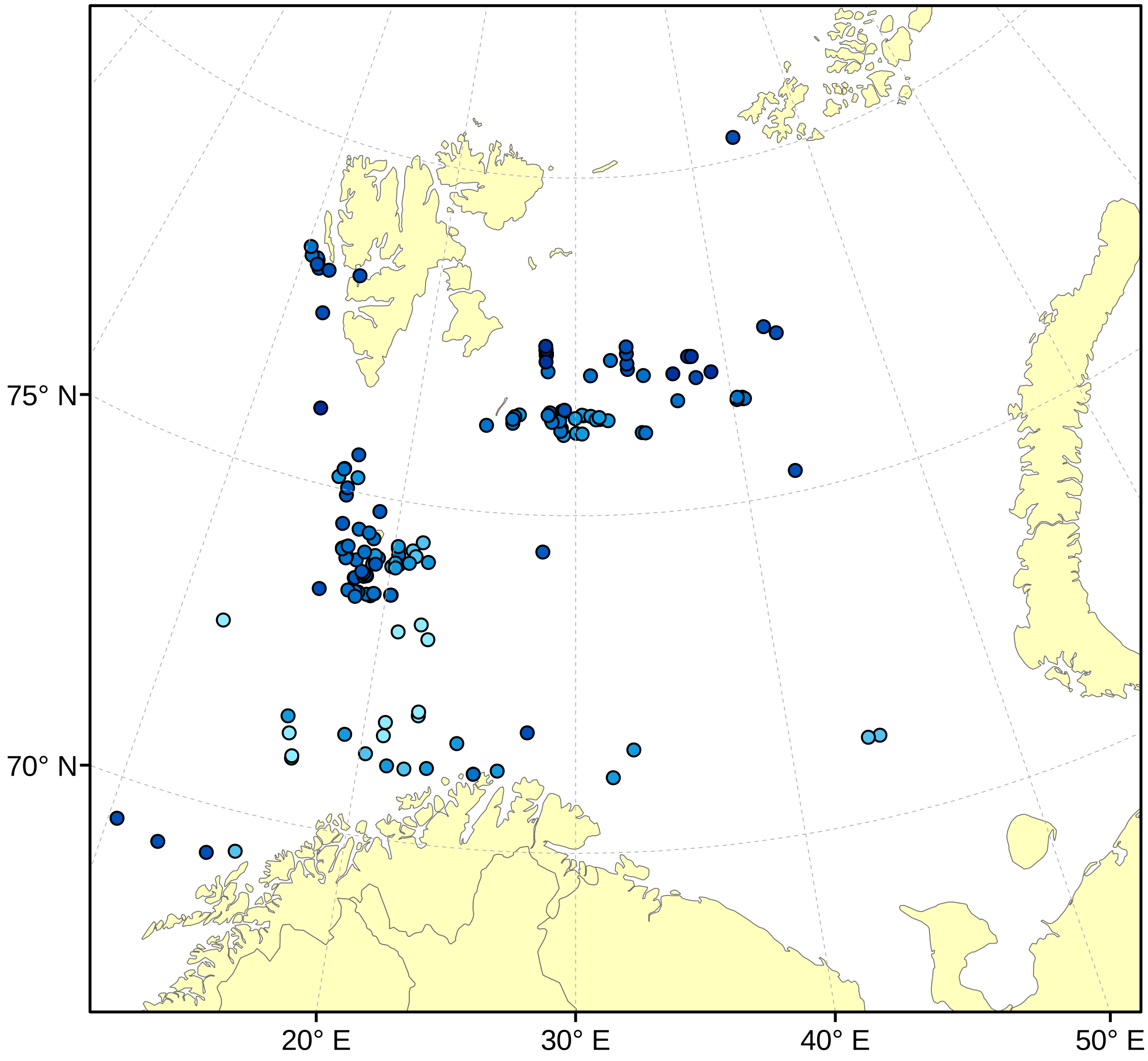


Figure 5.46. Observations of humpback whales in the Barents Sea summer and autumn 2006. For colour codes, see legend Figure 5.43.

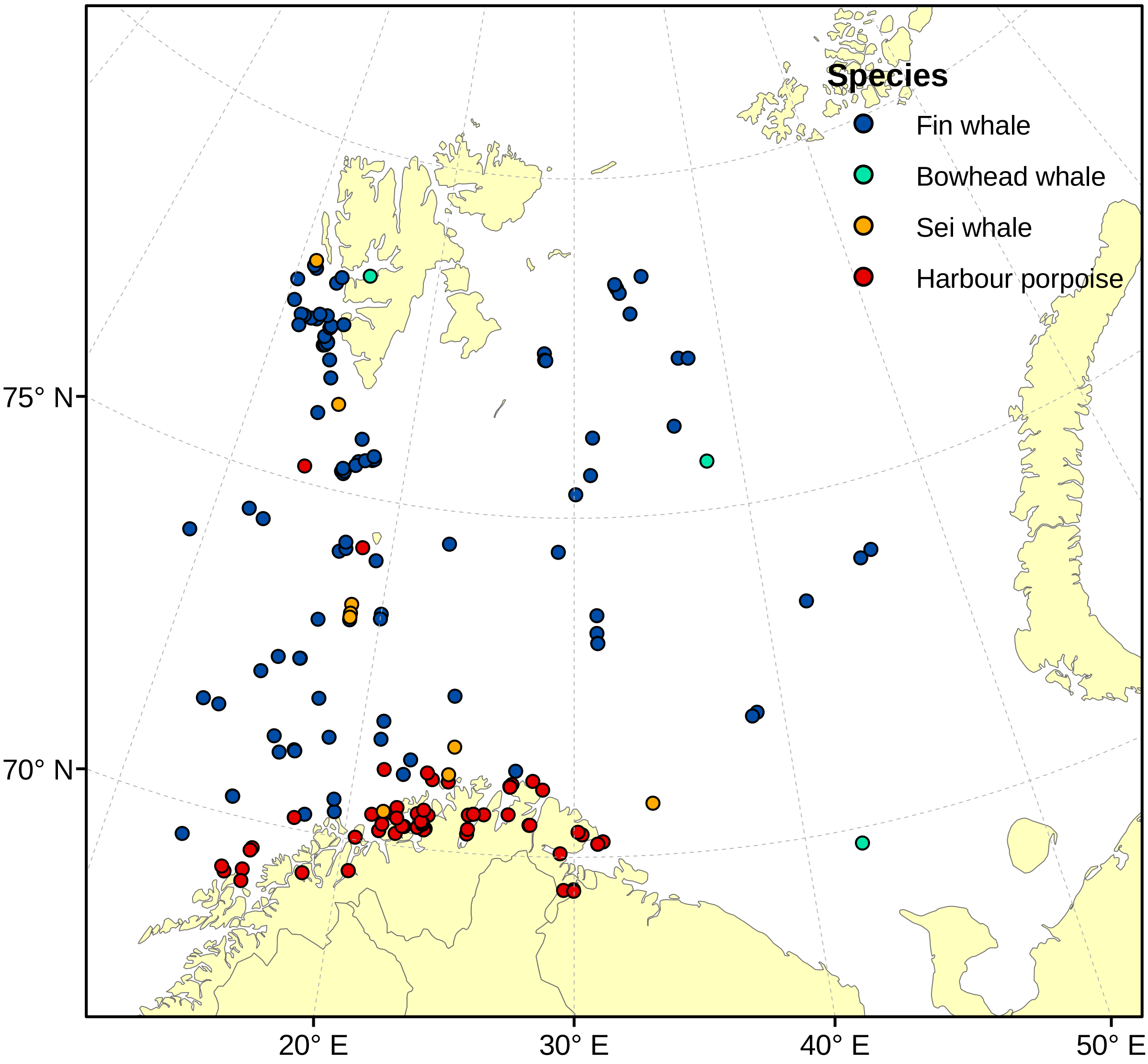


Figure 5.47. Observations of fin whales (blue), bowhead whale (green), sei whale (orange) and Harbour porpoise (red) in the Barents Sea summer and autumn 2006.

5.8.1.2 Sea birds

About 26,000 sea birds from 26 different species were observed during the autumn ecosystem cruise in the Barents Sea. Northern fulmar was the single most observed species comprising 51% of all observations. Northern fulmar and gulls are typical ship-followers; they are therefore likely overrepresented relative to the other seabird species observed.

The alcids were observed throughout the study area, but the abundance and species distribution varied geographically (Figure 5.48). Brunnich’s guillemot was the most common alcid species, and was observed in high concentrations in the north-eastern Barents Sea. The northern Barents Sea was inhabited by little auks, while in the southern Barents Sea puffins and common guillemots dominated. Northern fulmars were observed throughout the study area, although with highest densities in the western part (Figure 5.49). Among the gull species (Figure 5.49), kittiwakes dominated the abundances in the northern areas. Great black-backed gulls and herring gulls were observed in the southern Barents Sea. A few glaucous gulls were mainly observed in the central Barents Sea. Four species of skuas were observed (Figure 5.50); great, pomarine, long-tailed and arctic skua. Of these, pomarine and skua were the most abundant species. They were found in the eastern part of the Barents Sea. Arctic skua was found mainly in the western areas.

It is important to note that the observed distributions of seabirds shown in Figure 5.48-Figure 5.50 are not effort corrected. Due to unfavourable weather and light conditions observers were only actively searching during parts of the survey time, which may yield biased distribution maps.

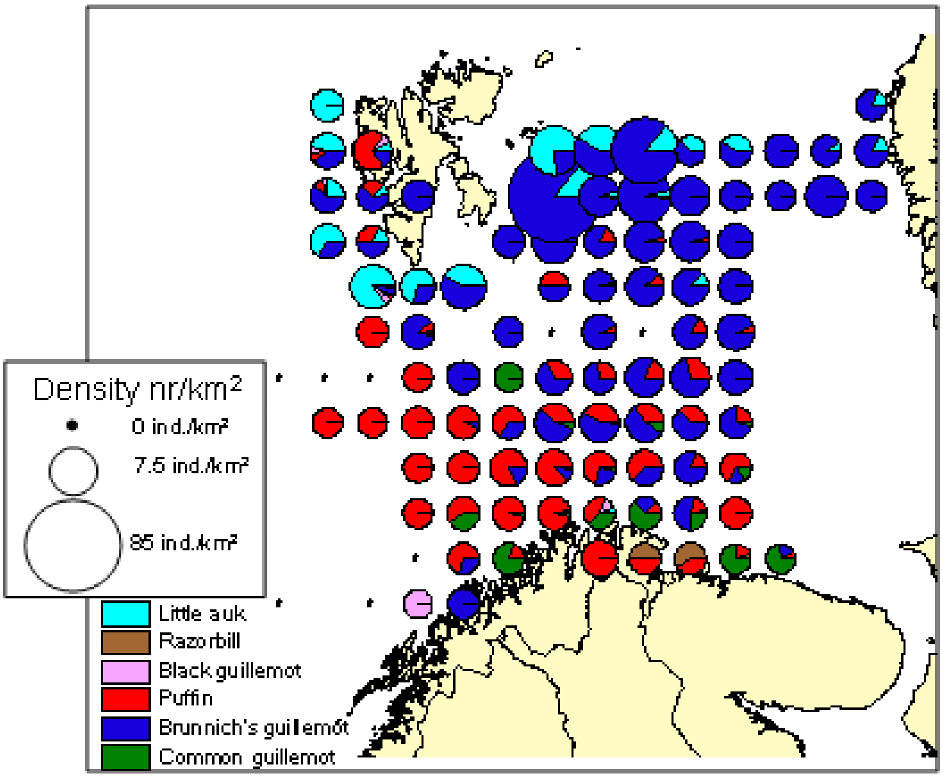


Figure 5.48. Distribution of auks observed during the Norwegian-Russian joint ecosystem survey in August-October 2006. Pie size reflects total density of auks (individuals per km^2), aggregated on a 100x100 km2 grid.

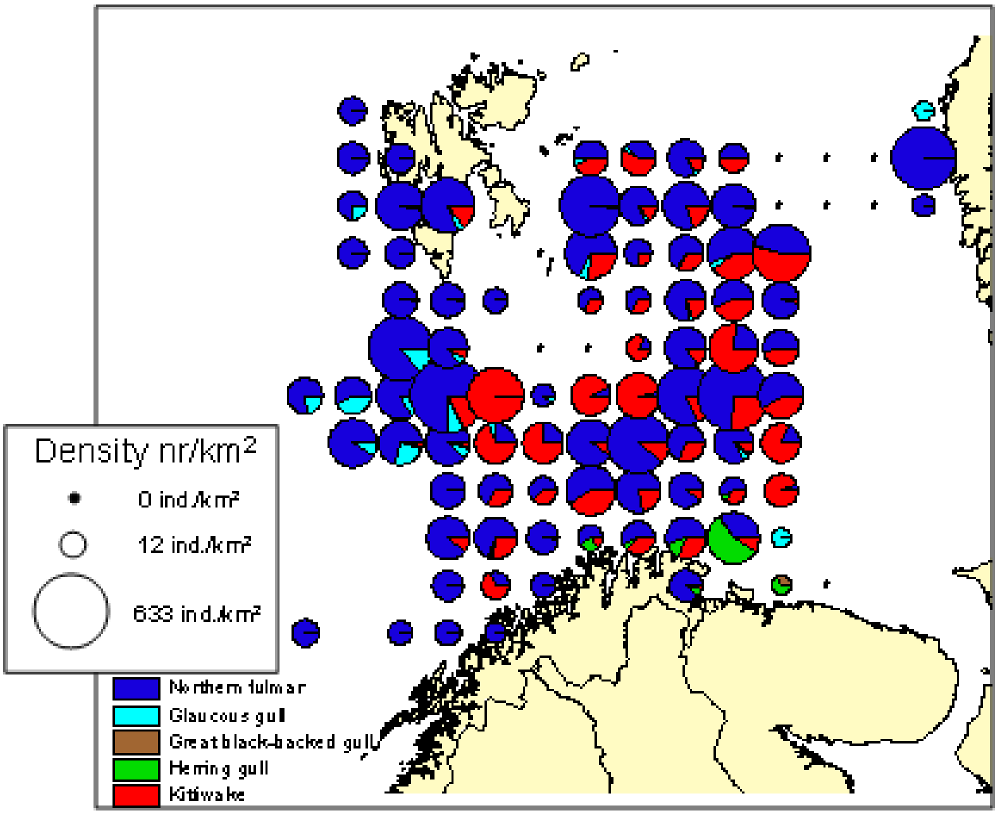


Figure 5.49. Distribution of gulls and northern fulmar observed during the Norwegian-Russian joint ecosystem survey in August-October 2006. Pie size reflects total density of auks (individuals per km^2), aggregated on a 100x100 km2 grid.

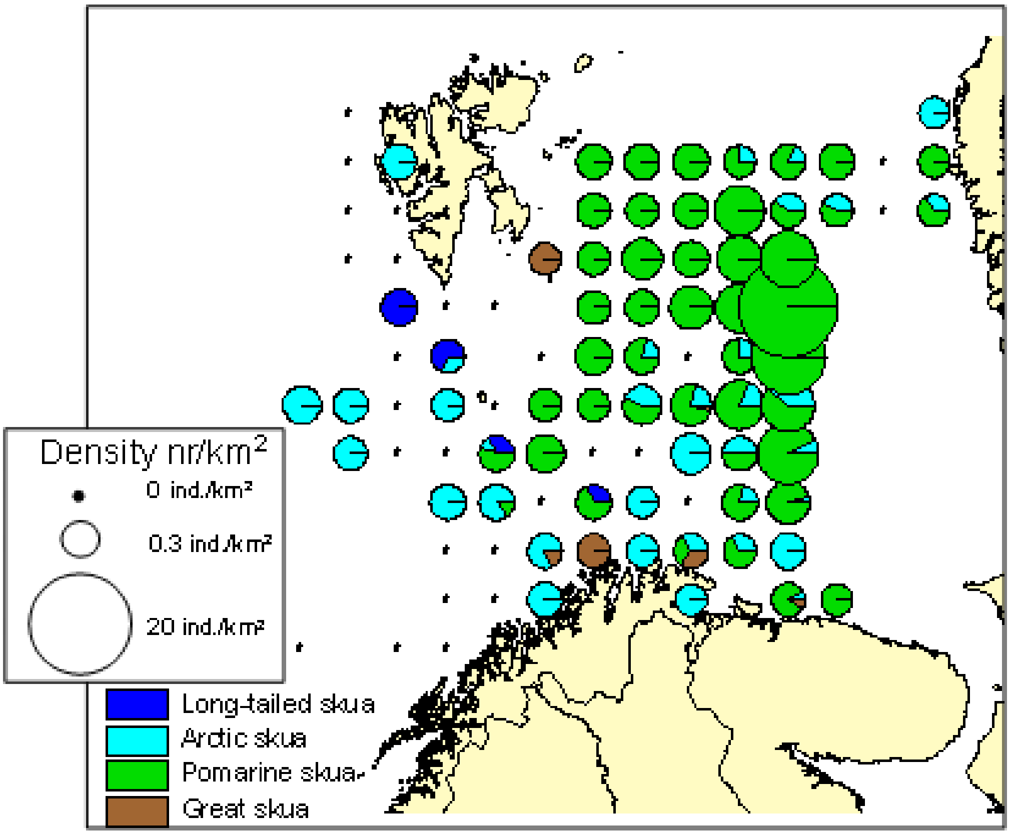


Figure 5.50. Distribution of skuas observed during the Norwegian-Russian joint ecosystem survey in August-October 2006. Pie size reflects total density of auks (individuals per km^2), aggregated on a 100x100 km2 grid.

5.8.2 Expected situation

As both marine mammals and seabirds common to the Barents Sea are long-lived species, their abundances are not likely to be heavily influenced by year-to-year fluctuations within the system. Rather, such fluctuations are more likely to cause distributional changes and changes in their diet. For instance, in a recent study on minke whales in the North, Norwegian and Barents Seas, Eriksen *et al.* (subm.) found that changes in distribution and habitat use of this generalist predator seemed to be associated with changes in prey abundance and distributions. Furthermore, the distribution of minke whales, a species occupying a range of thermal habitats, seemed not to be directly influenced by fluctuations in ocean climate. Thus, distributional changes as a response to changing ocean climate may only be observed in marine mammals and seabirds occurring in very specific habitats, e.g. such as ice associated species (e.g. bowhead whales, ice-associated seals and ivory gull), or at the extreme of species ranges, such as the warm water species common and striped dolphins. For the predominant marine mammals and sea birds in pelagic Barents Sea however, changes in prey abundance and distributions are likely the most important factor influencing the distributions and diet of these long-lived top predators, as they both track changing prey distributions and switch between prey species with different geographic distributions, such as krill, capelin and herring, depending on the availability of these species (Tjelmeland and Lindstrøm 2005, Fauchald and Erikstad 2002).

5.9 Ecological relations

By K. Drinkwater, B. Bogstad, A. V. Dolgov, Å. Høines, N. V. Muchina, E. L. Orlova and G. Ottersen

In an ecosystem there exists many links between species, or relations between a species and driving factors (such as temperature and inflow). Some are know, while other still remains to be discovered. Of those we know only a few is monitored. This section will only deal with known observed relations, with focus on those that deviates from the normal situation.

5.9.1 Current situation

5.9.1.1 Plankton and fish

In 2006 there was an increase in the abundance index for both 0-group herring and capelin. A particularly high 0-group index for herring in 2004 probably suggests an abundant stock of young herring in the Barents Sea also in 2006. Relatively high abundance of zooplankton in a greater part of the region suggests advective flux of zooplankton from the Norwegian Sea. In 2006 the average zooplankton biomass is above the long-term average, and the stock has been increasing since 2001. The capelin stock in 2006 was still at a low level, but slightly higher then in 2005.

During the Ecosystem survey in the Barents Sea in August-September 2005 stomach samples were collected from 0-group cod and haddock sampled by a pelagic trawl and bottom trawl (Table 5.5). Most of the 0-group cod from the bottom trawl samples were analyzed along with the stomach samples from older cod, while stomach samples from pelagic trawls and some other few samples from bottom trawl hauls were analyzed in detail at the IMR plankton laboratory. Total Fullness Index (TFI) was used a measure of stomach fullness in order to compare stomach fullness between species and different types of gear used for sampling. In general TFI for 0-group cod was highest in samples from pelagic trawl hauls, and TFI for 0-group cod were also higher then for 0-group haddock. Detailed stomach analysis show that calanoid copepods were the dominating prey items of 0-group cod (Figure 5.51). Among copepods *Calanus finmarchicus* clearly dominated, but on a few stations *Metridia longa* was also an important prey item. The plankton samples collected in the vicinity of the trawl hauls that contained 0-group specimens, show that *C. finmarchicus* dominated both in numbers and in terms of biomass in Atlantic water in the Barents Sea. In addition, the krill species *Thysanoessa inermis* and *Meganyctiphanes norvegica*, were important prey items for 0-group fish on several stations. Krill seems to be an important prey item in the central Barents Sea, where the abundance of krill is normally high. In a few instances fish was found in the stomachs of 0-group fish. For haddock, krill and copepods amounted to 32 and 31% of the stomach content respectively.

Table 5.5. Summary of 0-group cod and haddock stomach sampling from the Barents Sea Ecosystem Survey 2005. TFI: Total Fullness Index.

Species	Gear	No. Fish	No. Stations	Mean length (cm)	Mean weight (g)	Mean TFI
Cod	Pelagic	418	42	8.9	5.5	0.25
Cod	Bottom	164	115	9.0	6.4	0.10
Haddock	Pelagic	93	13	10.3	9.8	0.16

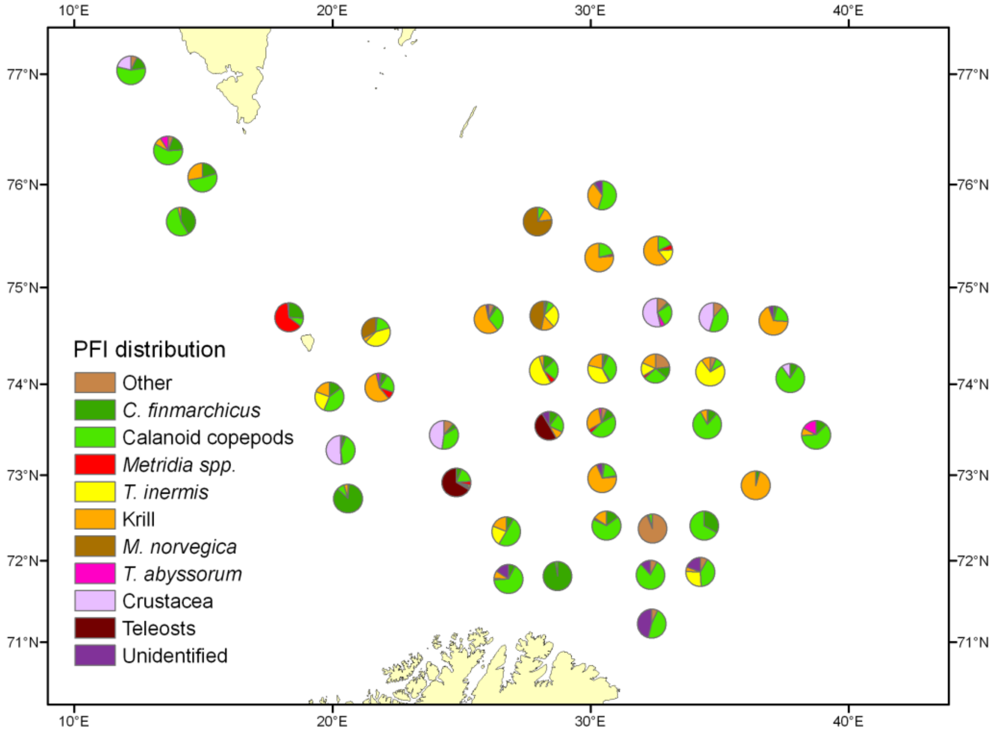


Figure 5.51. Relative distribution of prey in stomachs of 0-group cod caught by pelagic trawl during the Ecosystem survey in the Barents Sea 2005.

5.9.2 Expected situation

Despite a low stock of capelin and suggested good supply of zooplankton to the Barents Sea the increase in zooplankton biomass is moderate, suggesting increased grazing on zooplankton from other fish components of the ecosystem. On the other hand, the zooplankton stays mainly in the deeper part of the water column during August-September, as the *Calanus* component mainly has migrated to deeper waters to overwinter, hence is less available to zooplankton feeding fish. However, the larger the overwintering stock of zooplankton, the greater production of eggs and larvae can be expected next spring if conditions are otherwise favorable. Hence, the initial condition for local production in 2007 seems satisfactory. A high production of zooplankton is also beneficial to organisms that live on or in close association with the bottom. Interaction between plankton and such organisms will be higher if the amount of plankton in the near bottom region increase and this occur both during regular vertical migration and when zooplankton migrate towards the bottom region to overwinter. Also a higher sedimentation of organic material can be expected if a continuous high biomass of plankton is present in the water column.

The oscillations of the physical climate of the Barents Sea have an impact on biological processes. In addition, changes in predation pressure may have a significant impact in some years, e.g. capelin predation on zooplankton. Predators feeding on zooplankton in the Atlantic/subarctic waters would benefit, as warming conditions will provide optimal conditions also for zooplankton growth. However, the warming conditions of the Barents Sea may have a negative impact on the abundance and distribution of arctic zooplankton species, as well as their predators. Published results how that the abundance of the true arctic amphipod, *T. libellula* significantly dependent on the amount of Arctic water present in the Barents Sea (Dalpadado, 2002). In the high Arctic food web, zooplankton species such as *T. libellula* and *Calanus glacialis* play a significant role. The Barents Sea harp seal as well as sea birds, particularly the Brunnich´s guillemots, have been observed to feed mainly on *Themisto libellula*. Seabirds such as the little auk that rely on large Arctic *Calanus* species with high lipid content, may suffer if their primary prey declines due to a warmer ocean climate.

In recent years, the distribution patterns of capelin, herring and cod have changed. These changes have been attributed to changes in climate e.g. temperature (Anon, 2004; 2005). It is expected that many warm-water fish species such as blue whiting, horse mackerel, and haddock will expand to the north and east in the Barents Sea. Blue whiting, which have their main feeding grounds in the Norwegian Sea, feeding mainly on zooplankton, has now expanded into the western part of the Barents Sea, possibly due to the warming conditions in the area. These changes can have severe ecological implications for the ecosystem, as these new species entering the Barents Sea will compete for food with the existing native species.

5.10 Long-term trends

By K. Drinkwater, E. Johanessen, L. L. Jørgensen and J. E. Stiansen

5.10.1 Projections of the response to future climate change

The Intergovernmental Panel on Climate Change (IPCC) recently completed an evaluation of the evidence for and impacts of anthropogenic climate change (IPCC, 2007). Included as part of the IPCC exercise future climate scenarios were produced by several different coupled ocean-atmosphere Global Circulation Models. One of these was from the Bjerknes Center for Climate Research (BCCR) in Bergen, which is called the Bergen Climate Model (BCM). While the recent IPCC runs with the BCM showed improvements in some areas of the globe from earlier runs, the results for the Barents showed more ice than is observed resulting in colder temperatures and so the results are not considered as good as earlier BCM results (A. Sorteberg, BCCR, Bergen). While efforts are underway to rectify this situation through improvements in the BCM and to develop more regional models, for the following discussion on the possible impacts of future climate change, we consider the projections of Furvik et al. (2002) based on earlier BCM results to be the best available at present.

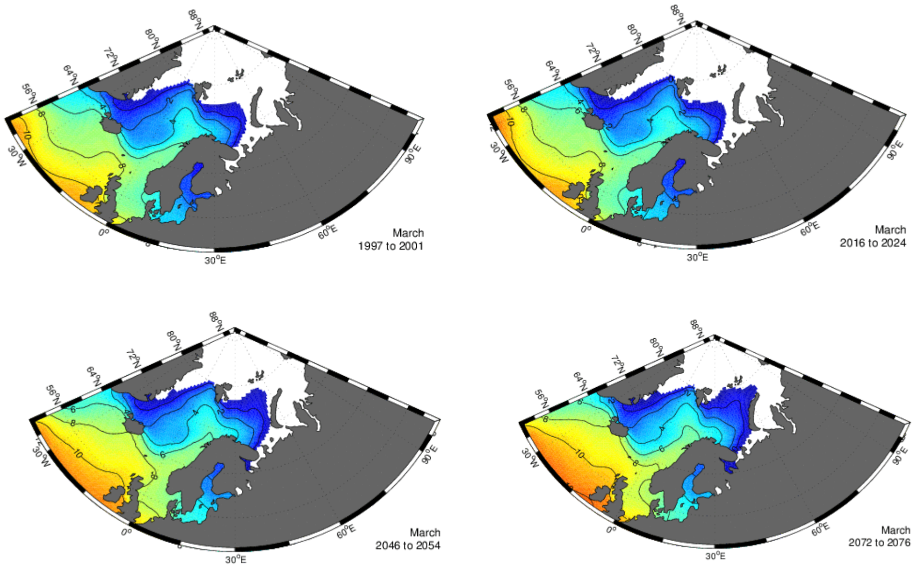


Figure 5.52. Historical and forecast sea surface temperatures and sea ice during March based on the Bergen Climate Model (taken from Furevik et al. 2002).

By 2080, Furevik et al. (2002) suggest surface ocean temperatures will warm 1° to 2°C in the Barents Sea (Figure 5.52), winter sea ice will almost disappear, Atlantic waters will spread farther eastward and northward, there will be more continental runoff but it will be partially compensated by inflow of high salinity Atlantic water, and the surface mixed-layer depth will increase due to stronger winds. Modelling studies (Slagstad and Wassmann, 1996) suggest primary production levels are 400% higher in ice-free regions in a warm year compared to when these same areas are ice-covered. Relative to the entire Barents Sea region, reduced ice cover will result in between 8% (Ellingsen et al., in press) to 30% (Slagstad and Wassmann, 1996) increase in primary production in years free of summer ice. This is due to a combination of higher light levels in areas of decreased ice extent and higher nutrient levels in the Atlantic waters where they extended northward and eastward. The biomass of Atlantic species of zooplankton, such as *Calanus finmarchicus*, is expected to increase (Ellingsen et al., in press) due to both higher transport into the Barents through higher inflow of warm Atlantic water (Stenevik and Sundby, 2007) and to faster turnover rates due to the higher temperatures, as suggested by Tittensor et al. (2003) for the Labrador Sea. Model studies show that higher primary production tends to lead to an increase in cod recruitment in the Barents Sea (Svendsen et al., in press). Improved growth rates together with the expected increased recruitment will lead to increased fish yields, although this will depend to a large degree upon the future fishing intensity. The higher overall production is expected to produce increased catches of cod, haddock and other species (ACIA, 2005). More fish will spawn farther north, as has been observed for cod (Drinkwater 2005), and new spawning sites will likely be established. Herring and blue whiting will spread farther eastward and salmon abundance likely will increase in Russian waters as previously observed (Lajus et al. 2005) and also extend to northern Svalbard. Capelin will follow the Polar Front farther to the northeast to feed and while they are expected to continue to spawn off northern Norway new spawning sites may be established in locations such as Svalbard and Novaya Zemlya. 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). Under the projected warming in the Barents Sea, Atlantic Water species of fish and benthos are expected to extend farther east and north (Drinkwater, 2005; ACIA, 2005; Stenevik and Sundby, 2007).

5.10.2 Present indications of a ecosystem regime shift ?

The recent warming period in the North Atlantic region (including the Barents Sea) opens for the question about regime shifts in the ecosystem. The question if the ecosystem has reached a different state, which may be irreversible, or is just at a maximum in a natural cycle, is hard to evaluate. However, a similar warming period took place in the 1930's. The whole ecosystem responds to long-term changes (e.g. in temperature). Higher temperatures may lead to changed distribution of many species. In recent years the blue whiting have been numerous in the western part of the Barents Sea, which is probably an effect of this warming.

However, a regime shift may also be trigged by changes in harvesting of predators in the system, thus resulting in a cascade effect in the food chain, and thereby altering of the composition structure in the ecosystem.

Figure 5.53 show a collection of various time series from the Barents Sea ecosystem. Each time series have been normalised, and positive and negative anomalies coloured red and blue, respectively. From this figure it looks like several, but not all, factors responds within a few years to oscillatory cycles in the system. If this is due to climatic or harvesting mechanisms are not known, but on the other hand it seams to be no sign of an irreversible regime shift or strong steady change in the ecosystem as a whole. However, the future climate scenarios given by the recent IPCC report (IPCC, 2007) give in most of the cases a temperature regime that is much higher than previously observed in the Barents Sea. That means that one of the major ecosystem driving mechanisms moves into a range in which we have little knowledge on how the ecosystem as a whole will respond. In that sence a regime shift in the future cannot be ruled out.

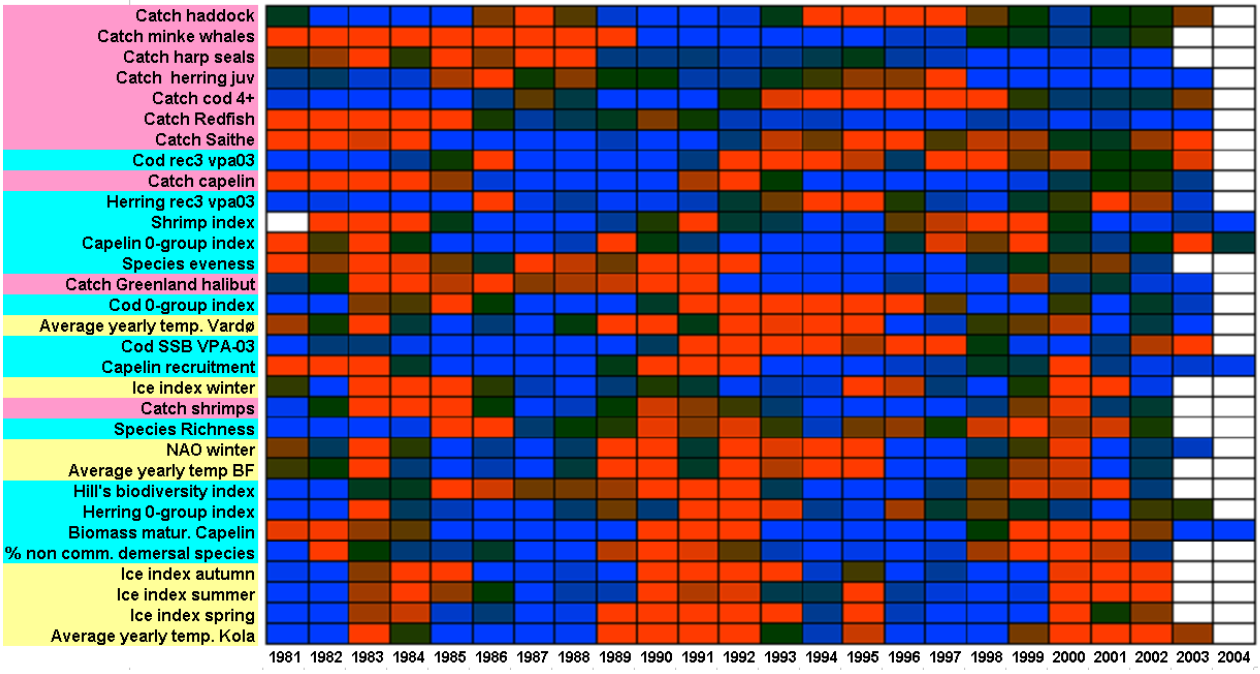


Figure 5.53. Normalized time series from the Barents Sea Ecosystem 1981 to 2004. Blue color is negative deviation and red colour is positive deviations. The colouring of the names on the left side reflect type of time series; Red is catch, yellow is climate and green is other biological time series.

5.10.3 Benthos and climatic change

Climate change resulting in altered composition of Arctic and Atlantic water masses, and their relative contributions in mixed waters, will influence the both the location and hydrographic properties in the transition zone between the Arctic Region and the Eastern North Atlantic Boreal Region, with changes in the distribution of their associated organisms (Blacker 1957). Conspicuous echinoderms and bivalves with Atlantic affinities, which have recently established self-sustaining populations in areas previously defined as the Arctic region are indicators of the recent increases in temperature. If the warming trend continues in the Barents Sea in the coming century, southern species will become more frequent than now 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. Such changes will affect benthic production (i.e. food for demersal fishes and other vertebrates) and may therefore have severe management implications.

Future fluctuations in zoobenthic communities in part will be related to the temperature tolerance of the animals as well as the future temperature of the seawater. Whereas a majority of the boreal forms have planktonic larvae that need a fairly long period to mature, arctic species do not (Torson, 1950). Consequently, boreal species should be quick to spread with warm currents in periods with warming, whereas the more stenothermal arctic species may 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, at least for some years. If warming happens in the Barents Sea in the coming century, thermophilic species will become more frequent than now. This will essentially force changes to occur in zoobenthos community structure and ts functional characteristics as well, especially in coastal areas.

6 Ecosystem information potential for improvement of advice for sustainable fisheries

By A. A. Filin, B. Bogstad, K. Drinkwater, H. Gjøsæter, V. A. Ivshin, J. E. Stiansen, O. V. Titov and S. Tjelmeland

6.1 Background

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 uncertainty of scientific recommendations for sustainable harvest levels. Improved advice for sustainable fisheries is considered as one of the main elements of the ecosystem approach to fisheries management in the Barents Sea (Bjordal and Boltnev 2004).

There are three primary processes as the underlying forces governing populations: competition, predation and environmental variability. Natural variation in recruitment, survival and growth of commercial species are consequences of these three processes. Effects of fishing are then superimposed on this ecological background. A close connection between environmental fluctuations and variation in population parameters of fish in the Barents Sea was suggested already by Helland-Hansen and Nansen (1909) and has been corroborated during recent years. Particularly year-to-year variability in sea temperature has been documented to influence Northeast Arctic cod through recruitment (Sætersdal and Loeng 1987; Ottersen and Sundby 1995; Tretyak *et al.* 1995), growth (Loeng *et al.* 1995; Michalsen *et al.* 1998; Ottersen and Loeng 2000) and distribution (Shevelev *et al.* 1987; Ottersen *et al*. 1998). However, also herring (Ottersen and Loeng 2000, Toresen and Østvedt 2000), haddock (Loeng et al. 1995; Ottersen and Loeng 2000) and capelin (Gjøsæter and Loeng 1987; Gjøsæter 1999) are affected by climatic fluctuations. All these relations between temperature variability and fish population parameters show the importance of taking environmental conditions into consideration in Barents Sea fish stock management. It seems especially important to focus on temperature impacts on recruitment processes since they are strongly influence year-class strength (Sætersdal and Loeng, 1987). Also the interaction between capelin, herring and gadoid species is important (Hamre, 1994). Strong indications of global warming also in the oceans as described by Barnett *et al*. (2001) and Levitus *et al*. (2001) gives further reason to take environmental factors into account.

Fishery management in the Barents Sea is conducted through the Joint Russian-Norwegian Fishery Commission, which is a political body at the governmental level and which acts based on advice from the International Council for Exploration of the Sea (ICES). Currently the stocks from the Barents Sea are dealt with by several assessment working groups at the ICES, although most of them are handled by the Arctic Fisheries Working Group (AFWG). 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 AFWG since 2002. The main aim of this is to include data on environmental and trophic interactions into management advice.

Different kinds of models could be used to make prognoses of the change in population parameters and distribution of commercial species in the Barents Sea under the influence of a variety of ecosystem factors. At present, predation by cod on cod, haddock and capelin is included in the assessment for those stocks. However, capelin is the only one of these stocks for which predation by cod is modeled in the prediction. There is a need for also including predation by cod in short/medium term stock predictions of cod, haddock and herring. Also, harvest control rules and precautionary reference points should be studied in a multispecies context.

Apart from ICES the joint IMR/PINRO study on development of ecosystem approach to the fisheries management in the Barents Sea is conducted at the request from Norwegian - Russian Fishery Commission. In 2003 the Commission 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. 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).

6.2 Methods and tools to implication of ecosystem information in fisheries management

While the need to take into account short- and long-term environmental variability is obvious, it is not always clear how to accomplish this. The main method for implication of ecosystem information into fisheries management decisions is through mathematical modelling. An alternative approach for including ecosystem information into prediction of stock development is qualitative analysis based on general knowledge, historical data and recent observations.

For the Barents Sea different types of models were developed to examine fisheries questions. The ultimate motivation of such fisheries models is to understand and inform decision-makers of the consequences of possible fishing activities. There are several examples of application of regression models, with prognostic possibility, of the change in population parameters and distribution of commercial species in the Barents Sea under the influence of variation environmental factors.

Development of complex multispecies models designed to improve fisheries management in the Barents Sea based on species interactions started in the mid-1980s. At first, the work focused on models that included a maximum number of species interacting through their trophic relations. This approach was used at IMR to develop such models as MULTSPEC, AGGMULT and SYSTMOD (Tjelmeland and Bogstad, 1998; Hamre and Hatlebakk, 1998). In PINRO this approach was employed for development of the MSVPA model (Korzhev and Dolgov, 1999). All these models can give quantitative characteristics of interactions between cod and other species in the Barents Sea and can be useful for addressing theoretical problems of multispecies management. However, the use of these models for practical tasks of fisheries management is limited by a high level of uncertainty in calculations due to assumptions employed in the models and incomplete data, which are needed for the estimation of model parameters. Therefore, since the second part of the 1990s some simpler models (in a structural sense) have been the priority. Benefits of multispecies models include: improved estimates of natural mortality and recruitment; better understanding of stock-recruitment relationships and variability in growth rates; and alternatives views on biological reference points.

Current and potential ecosystem information for application in the stock dynamics predictions and fisheries management advice for the Barents Sea through different approaches and models - are considered below.

6.2.1 Qualitative estimations of ecosystem impact on population parameters commercial species

The simplest approach for looking at the future development of the commercial fish stocks accounting ecosystem considerations is to give qualitatively assignments on different stock parameters from major impact factor. Then an overall effect on the specific stock can be given. The advantage of this approach in comparison with quantitative methods that it can potentially uses all available ecosystem information. The deficiency – is high subjectivism in estimations.

6.2.2 Statistical models

6.2.2.1 Recruitment of commercial fish

Predictions of the recruitment are essential for predicting harvest levels of fish stocks, both in a single-species and multi-species context. Traditionally prediction methods have been based on spawning stock biomass only and have not included effects of climate variability. Multiple linear regression models can be used to incorporate both climate and parental fish stock parameters. Especially interesting are the cases where there exists a time lag between the predictor and response variables as this provides the opportunity to make an early prediction.

Several statistical models, which use multiple linear regressions, have been developed for North East Arctic cod (e.g. Bulgakova, 2005; Stiansen *et al*., 2005; Titov *et al*., 2005, Svendsen *et al*., 2007). Stiansen et al. (2005) developed a model for the period 1984-2005, with 2 year prediction possibility:

$$R3 \sim Temp(-3) + Age1(-2) + MatBio(-2)$$

where R3 is the VPA age3 NEA cod (with cannibalism). Temp is the Kola yearly temperature (0-200m), Age1 is the winter survey bottom trawl index for cod age 1, and MatBio the maturing biomass of capelin. The number in parenthesis is the time lag in years. Two other similar models can be made by substituting the term Age1(-2) with Age2(-1) and Age 3(0), respectively (winter survey bottom trawl index for cod age 2 and age 3, respectively). Svendsen *et al.* (2007) used a model based on numerical model data from the ROMS hydro-dynamical model. The model is for the period 1985-2006, with 3 year prognosis possibility:

$$R3 \sim Phyto(-3) + Inflow(-3)$$

where R3 is the VPA age3 NEA cod (with cannibalism), Phyto is the modelled phytoplankton production in the whole Barents Sea and Inflow is the modelled inflow through the western entrance to the Barents Sea in the autumn. The number in parenthesis is the time lag in years.

In 2007 statistical models (Titov et al., 2005) were partially changed. Joint ecosystem autumn survey index for 0-group cod was replaced on winter survey bottom trawl index for cod age 1, age 2 and age 3.

The simplest approach for looking at the future development of the commercial fish stocks accounting ecosystem considerations is to give qualitatively assignments on different stock parameters from major impact factor. Then an overall effect on the specific stock can be given. The advantage of this approach in comparison with quantitative methods that it can potentially uses all available ecosystem information. The deficiency – is high subjectivism in estimations.

6.2.2.2 Maturation of cod

The decrease in capelin stock biomass potentially impacts the maturation dynamics of Northeast Arctic cod by delaying the onset of maturation and/or increasing the incidence of skipped spawning. The relationship between weight- and length-at-age shows that for a given length, weight-at-length is positively correlated with proportion mature-at-length for the period 1985-2001 (Marshall *et al*., 2004).

Estimates of weight-at-length were multiplied by the Russian liver condition index at length (Yaragina and Marshall, 2000) to derive estimates of liver weights in grams for cod at a standard length (see Marshall et al. 2004 for details of the calculation). This analysis indicated that for 1985-2001 there is a consistently significant, positive relationship between liver weight and proportion mature.

6.2.2.3 Growth of fish

Large interannual variations in growth rate are observed for all commercial species in the Barents Sea. The most important causes are temperature change, density dependence and changes in prey availability. Variation in growth rate can contribute substantially to variability in stock biomass. This needs to be taken into account when setting fishing targets and reference points. Variation in growth and condition can have a large impact on reproductive output.

Cod. The Northeast arctic cod is characterized by significant year-to-year variations in its growth rate. In different years the mean weight of fish at the same age may differ 2-3 times. Regressions of weight at age of cod to temperature, capelin and the cod stock itself are used in EcoCod model. The full documentation of these regressions is found on the web site www.assessment.imr.no/request/index.html.

Capelin. By using the data from the winter macro-plankton survey conducted by PINRO the most statistically significant relationship between length/weight of capelin and euphausid abundance indices was revealed for fish at age 2. The closest relationships between indices of euphausid abundance and absolute/relative increments in length and weight of capelin were registered in fish at the fourth year of life (age 3+). For younger age groups no statistically significant correlation coefficients were revealed. However, all regression equations had low determination coefficient.

By using the data from the autumn ecosystem survey, capelin growth in a given year is more closely correlated with the estimate of zooplankton abundance in the previous autumn than with that in the present autumn (Gjøsæter et al., 2002). Growth of the youngest capelin is well correlated with abundance of the smallest zooplankton, whereas growth of older capelin is more closely correlated with abundance of the larger zooplankton. Mean growth in length during the last growth season shows positive relationships with total zooplankton density for all age-classes. The correlation coefficients are generally low, but they are statistically significant for 1-, 2- and 4-year-olds. Growth rates of 3-year-old capelin during their last season do not correlate well with estimated total zooplankton density but the length of 1-year-olds, weight and growth were all significantly correlated with zooplankton density. Growth of 1- and 2-year-old capelin was negatively related to total capelin biomass.

6.2.3 Multispecies models

6.2.3.1 EcoCod

This model has been developed since 2005 as the main task of the first stage of the joint PINRO-IMR Programme of Estimation of Maximum Long-Term Yield of North-East Arctic Cod taking into account the effect of ecosystem factors (Filin and Tjelmeland, 2005). This 10-year research programme was initiated following a request from the Russian-Norwegian Fishery Commission. EcoCod is a stepwise extension of a single species model for cod (CodSim; Kovalev and Bogstad, 2005), where cod growth, maturation, cannibalism and recruitment is modeled, to a multispecies model. Preliminary sub-models for cod growth, fecundity and malformation of eggs have been implemented in EcoCod. EcoCod also contains a biomass-based cod-capelin-plankton sub-model. Recruitment scenarios from the herring assessment model SeaStar (Røttingen and Tjelmeland, 2003; Tjelmeland and Lindstrøm, 2005) will be used in the modeling of recruitment in the capelin sub-model.

6.2.3.2 Bifrost

The Bifrost (Boreal integrated fish resource optimization and simulation tool) is a multispecies model for the Barents Sea (Tjelmeland, 2005) with its main emphasis on cod-capelin dynamics. The prey items for cod are cod, capelin and other food. The predation model is estimated by comparing simulated consumption to consumption calculated from individual stomach content data using the dos Santos evacuation rate model with a parameterization where the initial meal size is excluded. The capelin partly shields the cod juveniles from cannibalism, and by including this effect the recruitment relation for cod is significantly improved.

Bifrost is used in connection with management of capelin by furnishing the tool used for calculating capelin quotas – CapTool – with historic replicates of parameters in the model for cod preying on capelin during January-March and parameters in the capelin maturation function, all of which are estimated in Bifrost.

The recruitment functions for cod and capelin are defined with the possibility of different forms, different probability functions for the error distribution, different parts of the year for using temperature data and different covariates including temperature, herring (for capelin recruitment) and cannibalism. For each historic replicate of September data and consumption-related data (replicates for the cod assessment are still missing) several hundred recruitment functions are estimated. During long-term simulations one historic replicate is first drawn, thereafter one recruitment relation for each species from the pool of recruitment relations previously estimated for that historic replicate, using Akaike's weights (Burnham and Anderson 2002).

For capelin, the influence from herring is invariably a covariate in the best recruitment relations, for cod temperature is invariably a covariate.

In prognostic mode Bifrost is coupled to the assessment model for herring – SeaStar (Tjelmeland and Lindstrøm, 2005) – and the negative effect of herring juveniles on capelin recruitment is modeled through the recruitment function for capelin. Bifrost is also used to evaluate cod-capelin-herring multispecies harvesting control rules through long-term simulation.

At present, work is conducted to incorporate the effect of harp seals into Bifrost. Detailed documentation of Bifrost can be found at the web site www.assessment.imr.no.

6.2.3.3 Gadget

A multi-species Gadget age-length structured model (www.hafro.is/gadget ; Begley and Howell, 2004, developed during the EU project dst^2 (2000-2003)), is being used for modeling the interactions between cod, herring, capelin and minke whale in the Barents Sea as part of the EU projects BECAUSE (2004-2007) and UNCOVER (2006-2010). This is a multi-area, multi-species model, focusing on predation interactions within the Barents Sea. The predator species are minke whale and cod, with capelin, immature cod, and juvenile herring as prey species. Krill is included as an exogenous food for minke whales. The cod model employed is based on the model presented at AFWG. So far, the model has been fitted to historical data on feeding, stock abundance and catches for the period 1985-2005. The model-data fit is shown in Figure 6.1 (stock abundance) and Figure 6.2 (whale diet composition). During 2007, forward simulations will be carried out in order to study the effect of various management strategies.

The modeling approach has many similarities to the MULTSPEC approach (Bogstad et al., 1997). Work is ongoing to enhance the modeling of recruitment processes during the EU project UNCOVER. An FLR routine has been written that can run Gadget models as FLR Operating Models. It is intended to explore this further during the UNCOVER project. This also gives the possibility of using Gadget as an operating model to test the performance of various assessment programs under a range of scenarios.

6.2.3.4 STOCOBAR

The STOCOBAR (STOck of COd in the BARents Sea) is a complex simulation model that describes stock dynamics of cod in the Barents Sea, which takes into accounts trophic interactions and environmental influence (Filin, 2005). It can be used for predictions and historical analysis of cod stock development as well as for estimation of effectiveness of different harvest strategies. Outputs from this model have been presented at AFWG since 2002.

The conceptual basis of the model consists of the following:

- a proportion of prey species in a predator's ration reflects the proportion of these species in the sea;
- maximum consumption by fish depends on their body weight and environment temperature;
- a coefficient of proportionality between real and maximum consumption by a predator is the function of available food;
- quantity of available food as a particular prey item is determined by the total biomass of prey in nature, a coefficient of its suitability as food and the coefficient of food competitiveness of the predator when consuming this prey;
- a coefficient of food suitability of prey for a predator is a coefficient of proportionality between prey portion in the predator stomach and their portion in nature in relation to all other categories of prey;
- a coefficient of intraspecific food competitiveness reflects the relative rate of consumption of the prey by specimens of given age group in comparison with specimens of other age groups;
- growth of fish is the function of initial body weight and body length, water temperature and ration expressed as energy units;
- maturation rate of cod is determined first of all by their linear growth and fatness.

The STOCOBAR model has no geographical resolution, i. e. the processes are simulated without area differentiation. The time-step of the model can be set to either one year or half a year. The model includes cod as predator and seven prey species of cod; capelin, shrimp, polar cod, herring, krill (euphausiids), haddock and young cod (cannibalism). All prey species except for shrimp and krill are divided into age groups. The four most common euphausiid species that occur in the Barents Sea are included in the model as one group without specification. Species structure of the model is not permanent and it is set according to the tasks of the model analysis and available input data. Therefore, based on common algorithms the model can be used in different structural modifications. It can be reduced from seven-species version to a simple version, which includes cod and capelin only. All calculations for cod in the model are carried out in cohort mode. The recruitment function is used for cod only.

Long-term estimations of the influence of ecosystem factors on the cod stock development are realized in the model by using stochastic ecosystem scenarios (Filin and Tjelmeland, 2005). A management strategy of the cod stock in the model is realized on the basis of a principles of the precautionary approach applied in the ICES. In accordance with that, the harvest control rules in the model are based on biological reference points (B_{lim}, B_{pa}, F_{lim}, F_{pa}).

The first version of STOCOBAR was developed at PINRO in 2001 and improvement of this model is continuing. It is planned to include uncertainties in the model framework. The description of the model algorithms is in the working documents of the AFWG in 2007 (Filin 2007). The work on the development of the STOCOBAR model is part of the Barents Sea Case Study within the EU project UNCOVER (2006-2010) and the joint PINRO-IMR

Program of Estimation of Maximum Long-Term Yield of North-East Arctic Cod taking into accounts the effect of ecosystem factors.

Figure 6.3-Figure 6.5 show the consistency of the modeled (from STOCOBAR) and observed cod food composition.

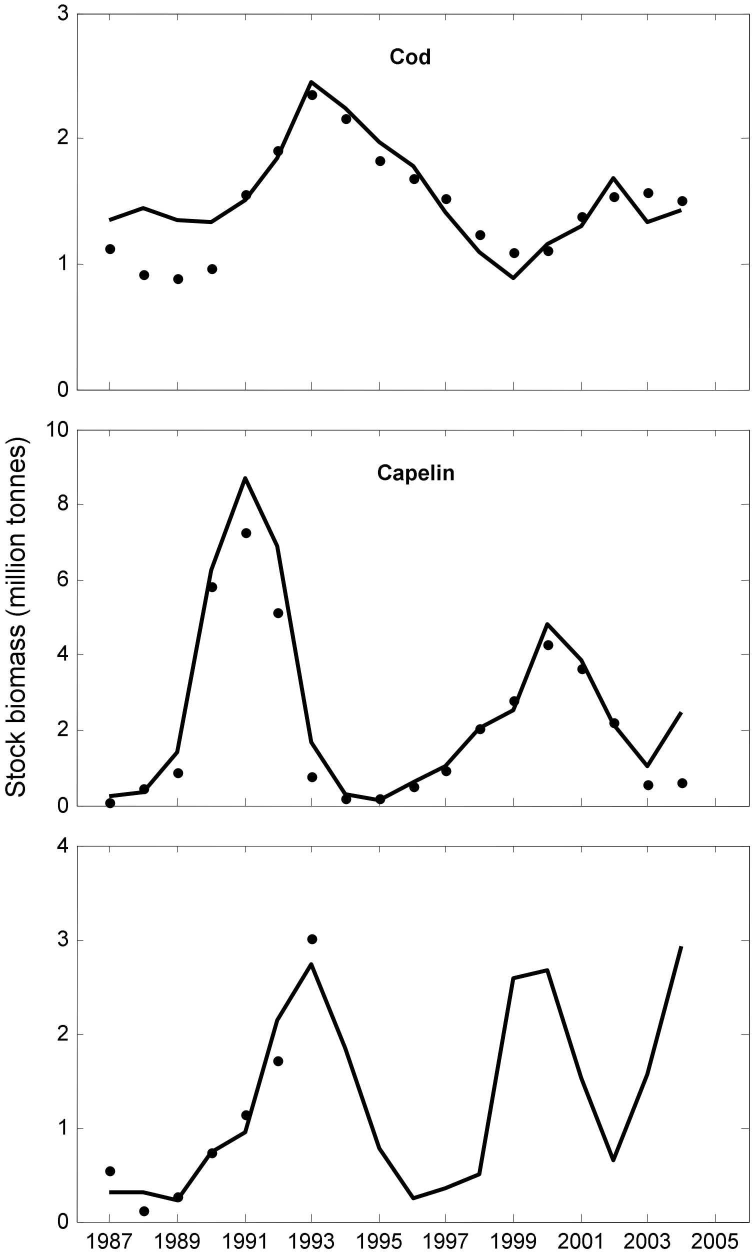


Figure 6.1. Results of Gadget multispecies runs. Predicted (lines) and biomass estimates (dots), taken from assessment, of cod 3+ (upper panel), capelin (mid panel) and juvenile herring (lower panel) in the period 1987-2004.

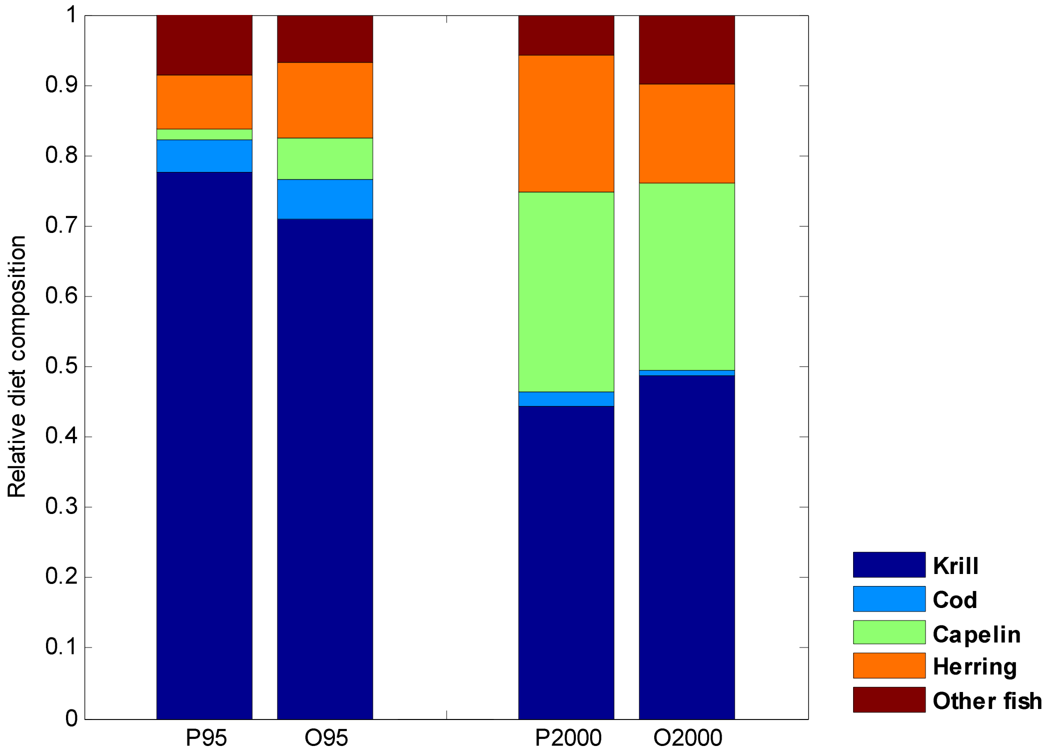


Figure 6.2. Results from Gadget runs. Predicted (P95 and P2000) and observed (O95 and O2000) whale diets in two years (1995 and 2000) of contrasting prey abundances.

6.2.4 Including data on cod predation into stock assessment of cod and haddock.

For the cod assessment annual stomach data have been used for estimating cannibalism, since the 1995 assessment. The cod stomach content data are taken from the joint PINRO-IMR stomach content database. The method used for calculation of the consumption is described by Bogstad and Mehl (1997). The procedure with an estimate of the number of cod consumed by cod (by year and prey age) based up stock estimates in the last assessment. Then the numbers consumed are added to the catches used for VPA tuning. The resulting stock then leads to new consumption estimates. This procedure is repeated until the consumed numbers for the latest year differed less than 1% from the previous iteration.

In order to build a matrix of natural mortality which includes predation, the fishing mortality estimated in the final XSA analyses is split into the mortality caused by the fishing fleet (true F) and the mortality caused by cod cannibalism (M2) by using the number caught by fishing and by cannibalism. The new natural mortality matrix is prepared by adding 0.2 (M1) to the M2. This new M matrix is used together with the new true Fs to run the final VPA.

The number by year and age of haddock eaten by cod is estimated after the cod assessment is finished, and then these numbers are added to the catches used for the VPA tuning. For haddock iterations are not needed.

6.2.5 Numerical models for simulation the drift of fish eggs and larvae

Numerical models have been used to simulate the drift of cod, capelin and herring larvae in the Barents Sea in order to find their dispersion area. Parameters in the model such as the location of spawning area, time of spawning and vertical distribution of eggs and larvae, as well as temperature, salinity and current information, are based on historical data and recent field observations. Simulations of the drift routes are performed by means of tracers representing the fish larvae.

6.3 Operational estimations of impact ecosystem factors on fish stock dynamics in the Barents Sea

6.3.1 Short- and medium-term prognosis

6.3.1.1 Prediction of NEA cod stock parameters at the 2007-2009 by STOCOBAR model

Table 6.1 presents the prognosis of cod stock parameters for 2006-2009 from the STOCOBAR model, where 2005 was used as initial year. The model parameters were estimated from historical data (1984-2004). The input data are presented in Table 6.2. Prognosis of the current and expected capelin stock was derived using data from the capelin assessment (Anon., 2007). The PINRO prognosis on annual temperature on Kola section for 2007 and 2008 was used in model runs. For the period 2007-2008 an average of the previous three years were used for the fishing mortality and recruitment of cod at age 1.

According to the prognosis strong changes in cod growth during 2007-2008 are not expected and will remain around the long-term mean. The negative consequences of reduced numbers of capelin on cod growth for age 4-7 are likely compensated by high temperature that positively affects cod growth.

6.3.1.2 Prediction of NEA cod recruitment

Prognoses from existing models are shown in Table 6.3. Figure 6.6 and Figure 6.7 show the consistency of the modeled and observed data. According to multiple regressions, which include both stock and environmental parameters, the cod recruitment in 2007 is expected to be close to long-term mean and above it in 2008-2009. The predicted cod recruitment by multiple regressions is more optimistic compared with cod recruitment used in the assessment of AFWG (Anon, 2007).

6.3.1.3 Expected stock parameters based on qualitative analysis of ecosystem impact

The overall effect, together with the impact ecosystem factors on the cod stock and capelin stock parameters are shown in Table 6.4. According to qualitative analysis including the impact of different ecosystem factors, the growth, maturation and cannibalism in cod stock is expected to be around the long-term mean in the Barents Sea in 2007. For the capelin, the growth, maturation and natural mortality are expected at to be well above the long-term mean.

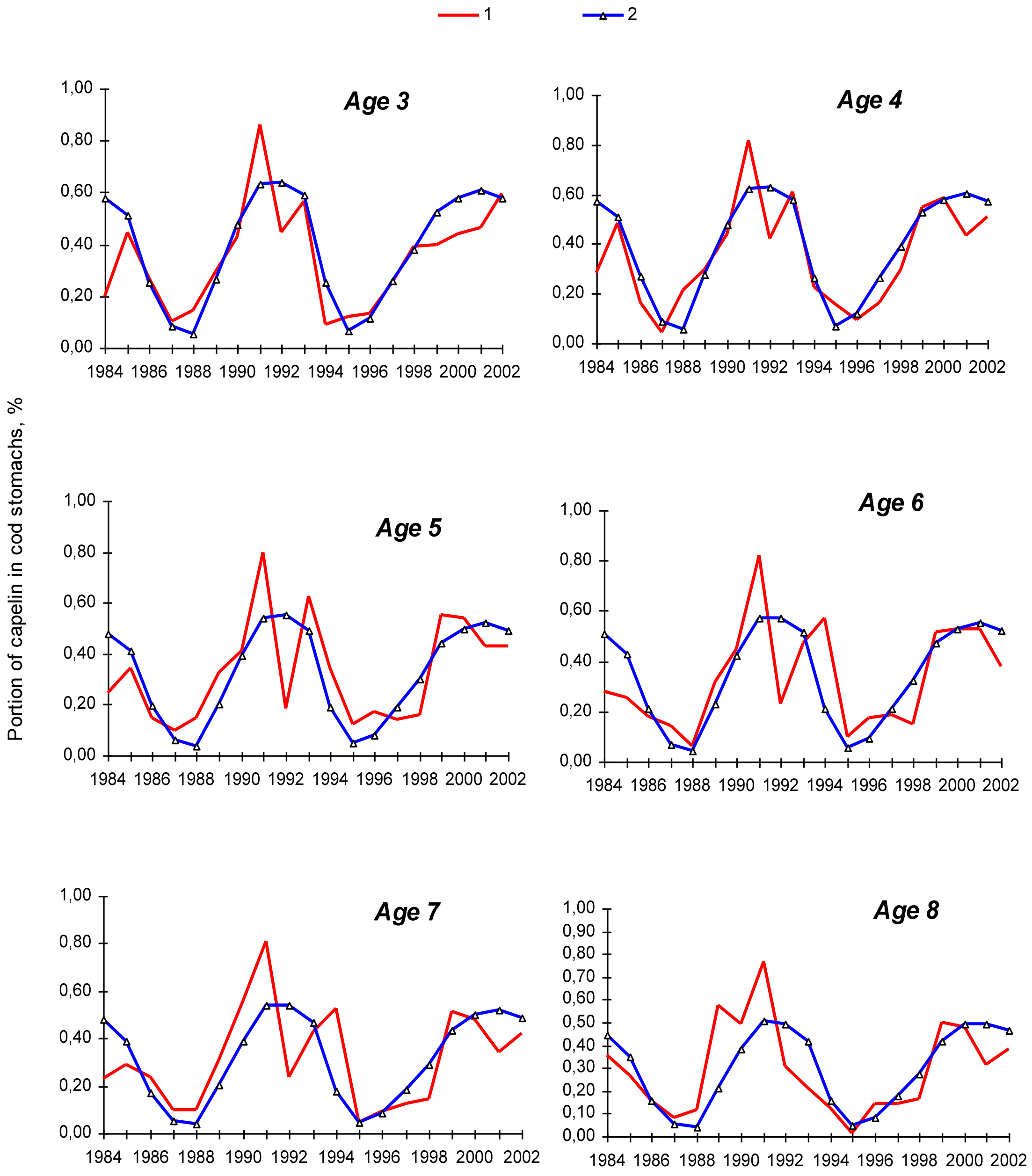


Figure 6.3. Consistency between the observed and simulated (STOCOBAR) portion of capelin in cod stomachs: red is observed, blue is simulated

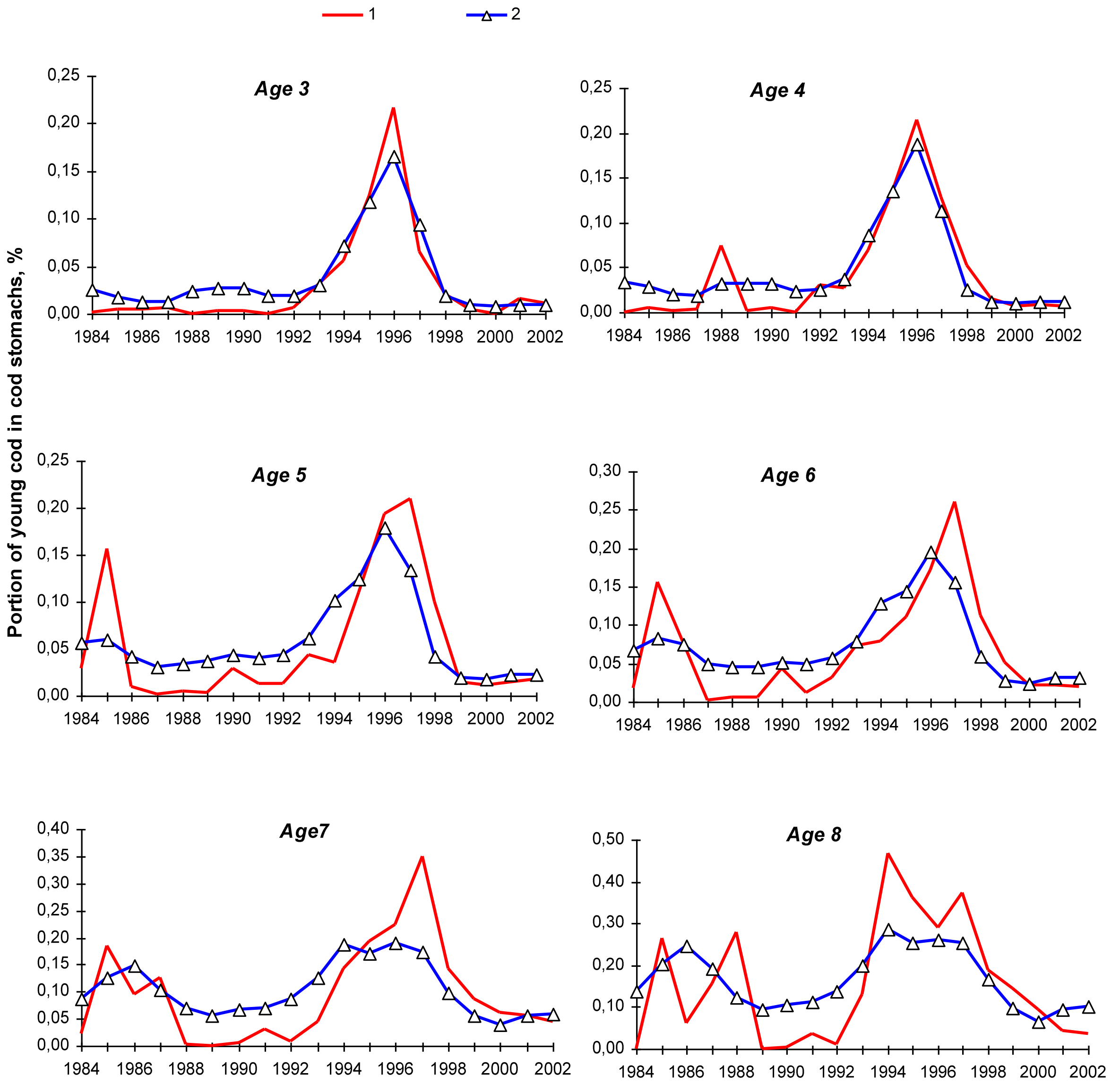
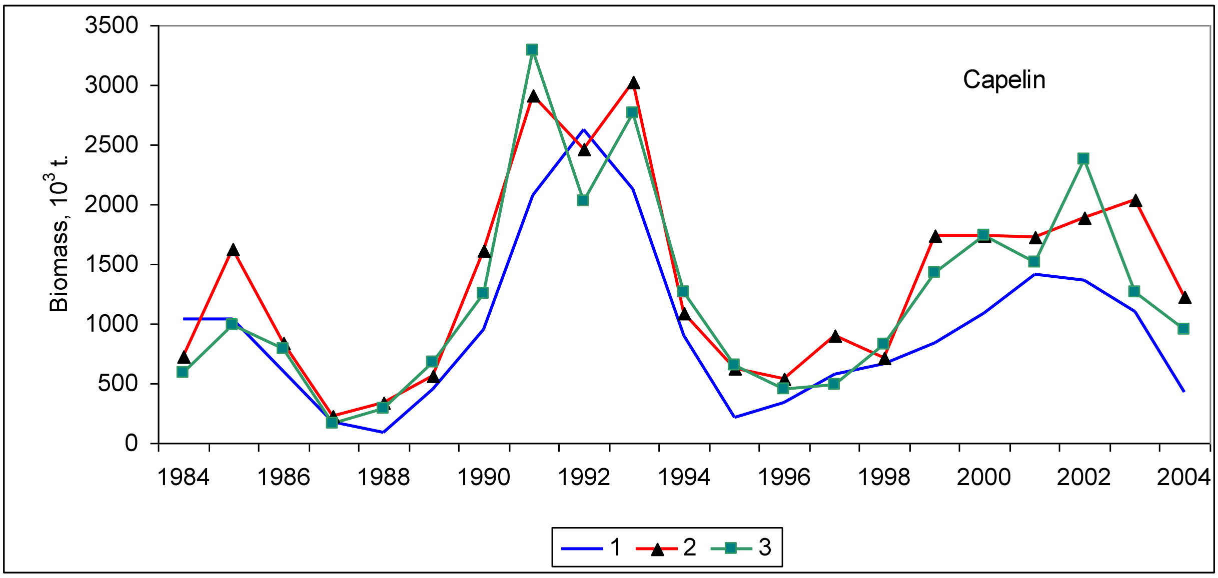


Figure 6.4. Consistency between the observed and simulated (STOCOBAR) portion of young cod in cod stomachs: red is observed, blue is simulated.



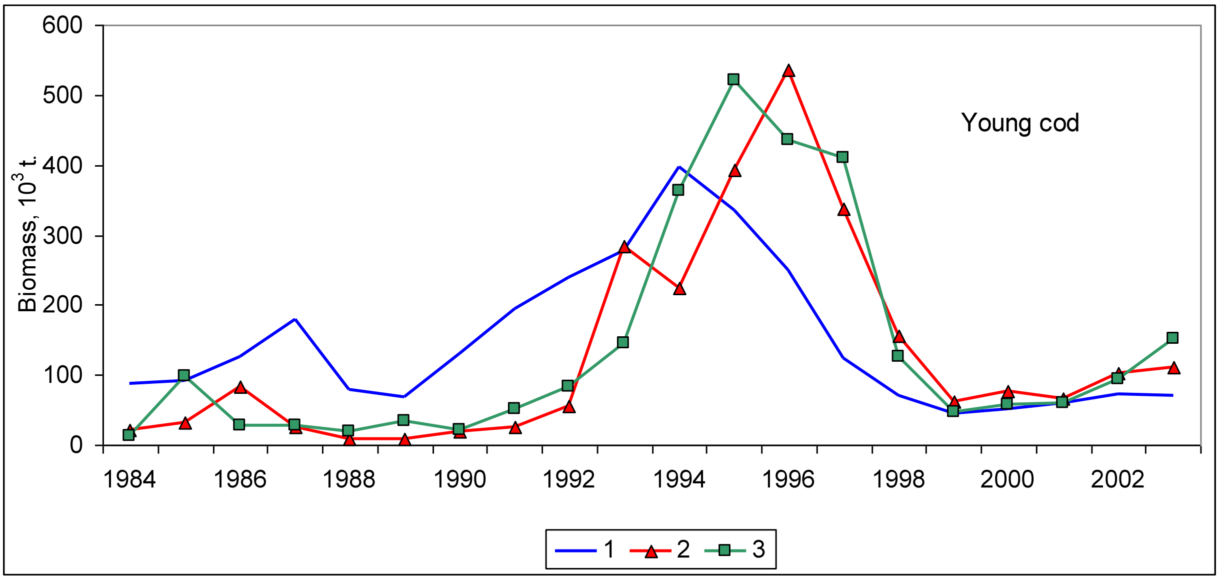


Figure 6.5. Annual consumption by cod of capelin (upper panel) and young cod (lower panel) in comparison with estimations of AFWG; Curve 1 is from calculation by STOCOBAR, curve 2 is estimation derived from report of AFWG 2006 (data from PINRO), curve 3 is estimation derived from report of AFWG 2006 (data from IMR).

Table 6.1. Prognoses of stock parameters of cod at the 2007-2009 by STOCOBAR model.

Age	Weight in stock, kg			Weight in catch, kg			Length in stock cm			Fatness %		
	2007	2008	2009	2007	2008	2009	2007	2008	2009	2007	2008	2009
2	0,07	0,06	0,06				20,1	20,9	22,4			
3	0,20	0,21	0,15				30,6	29,0	31,4			
4	0,59	0,56	0,54	1,04	1,00	0,83	39,4	40,7	39,1			
5	1,28	1,26	1,17	1,68	1,72	1,51	51,2	49,6	50,8	4,56	4,86	4,63
6	1,92	2,15	2,05	2,54	2,44	2,73	62,8	60,8	59,8	4,65	4,72	4,88
7	3,18	3,25	3,37	3,54	3,64	3,54	71,5	72,1	70,2	4,70	4,62	4,70
8	4,72	4,99	4,87	5,35	5,23	5,33	81,0	80,2	80,6	5,46	5,47	5,47
9	6,40	7,41	7,46	6,91	6,94	6,81	89,7	88,5	87,9			
10	8,13	8,92	9,60	7,91	8,42	8,48	92,4	89,7	88,5			

Age	Portion of mature fish			Ration kg			portion of capelin in cod diet	
	2007	2008	2009	2007	2008	2009	2007	2008
2	0	0	0	0,20	0,30	0,47		
3	0	0	0	0,85	0,63	0,97	0,13	0,17
4	0,01	0,01	0,01	1,86	1,79	1,47	0,27	0,34
5	0,05	0,06	0,06	3,31	3,50	2,97	0,27	0,33
6	0,28	0,28	0,27	5,23	5,00	5,72	0,20	0,25
7	0,59	0,59	0,62	7,31	7,44	7,26	0,21	0,27
8	0,80	0,82	0,81	13,93	13,51	13,79	0,21	0,27
9	0,92	0,93	0,94	18,89	18,82	18,52	0,21	0,28
10	1	1	1	21,89	22,89	23,09	0,16	0,21

Table 6.2. Input data used in the prognosis on cod stock parameters by STOCOBAR.

Data	2006	2007	2008
Weight at age 1	0,010	0,015	0,015
Abundance at age 1	$1216*10^6$	$1216*10^6$	$1216*10^6$
Capelin stock size	$549*10^3$	$611*10^3$	$1757*10^3$
Temperature	5,1	4,6	4,5

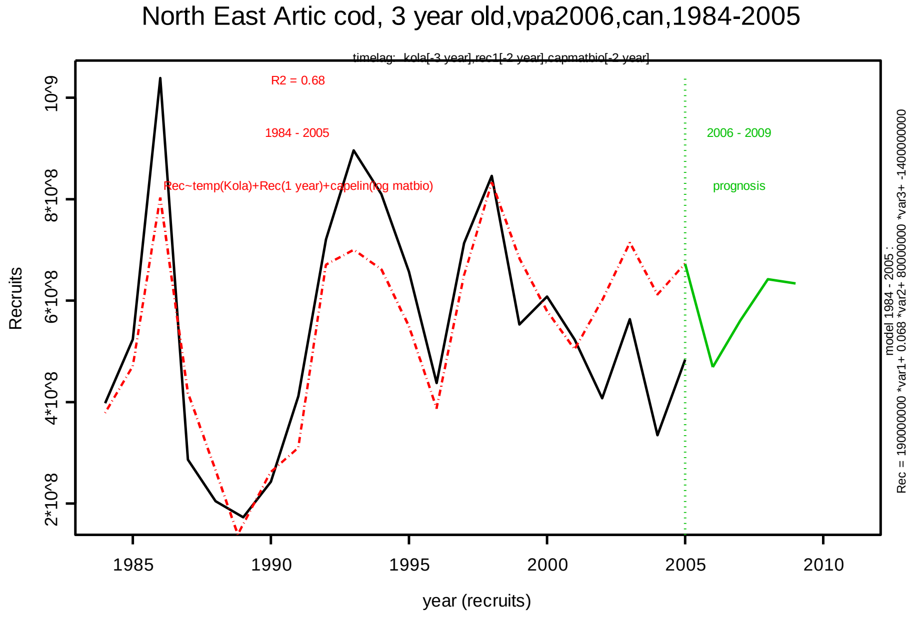


Figure 6.6. Modelled age 3 cod recruitment from Stiansen et al. (2005).

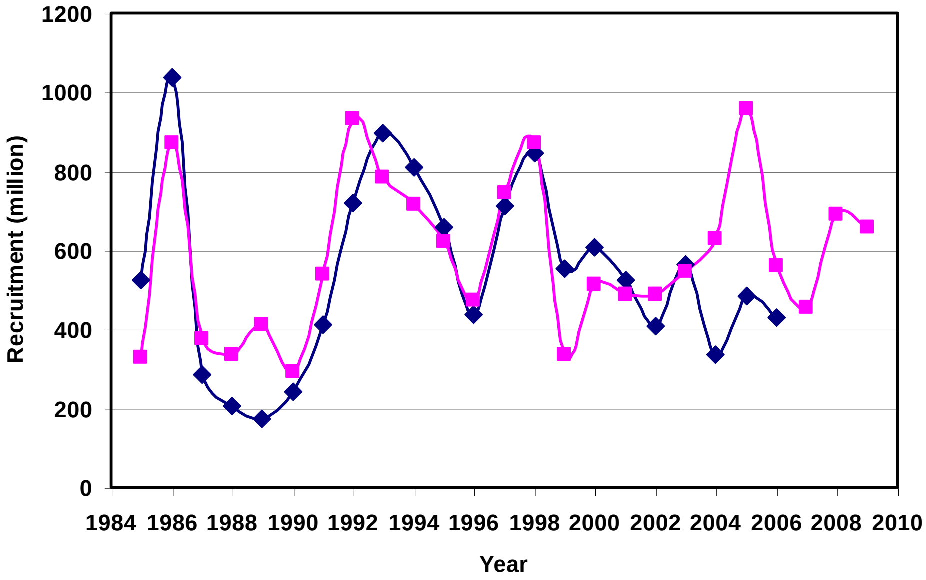


Figure 6.7. Modelled age 3 cod recruitment from Svendsen at al. (submitted).

Table 6.3. Overview of available recruitment models prognoses together with the 2006 assessment estimates (Anon 2007). Note that the given month in the fifth column indicates when the prognoses can be extended for another year.

Model	Species	Variable	Prognostic years	Prognoses available	2007 Prognoses	2008 Prognoses	2009 Prognoses	Unit
Titov (WD 16, AFWG 2005)	NEA cod	Recruits (age 3)	4	At assessment	760[**]	842[**]	380[**]	*10^{6}
Titov (WD 16, AFWG 2005), improved in 2007	NEA cod	Recruits (age 3)	3	At assessment	556 [**]	576[**]	200[**]	*10^{6}
Titov (WD 16, AFWG 2005), improved in 2007	NEA cod	Recruits (age 3)	2	At assessment	672[**]	575[**]		*10^{6}
Titov (WD 16, AFWG 2005), improved in 2007	NEA cod	Recruits (age 3)	1	At assessment	507[**]			*10^{6}
Titov (WD 16, AFWG 2005)	Barents Sea capelin	Recruits (age 1)	2	At assessment	37[**]	137[**]		*10^{9}
Titov (WD 16, AFWG 2005)	Barents sea capelin	Recruits (age 1)	1	At assessment	135[**]			*10^{9}
Bulgakova (WD20, AFWG 2005)	NEA cod	Recruits (age 3)	3	Before assessment	532 [*]			*10^{6}
Stiansen et al., WD14	NEA cod	Recruits (age 3)	2 (3 [1])	November (March [1])	561	642	634 [1]	*10^{6}
Stiansen et al., WD14	NEA cod	Recruits (age 3)	1 (2 [1])	November (March [1])	462	517 [1]		*10^{6}
Stiansen et al., WD14	NEA cod	Recruits (age 3)	0 (1 [1])	November (March [1])	559 [1]			*10^{6}
Svendsen et al WD 14	NEA cod	Recruits (age 3)	3	Februar	455	689	659	*10^{6}
Gadget Assessment 2006	NEA cod	Recruits (age 3)	1	At assessment	229			*10^{6}
RCT3 Assessment 2007	NEA cod	Recruits (age 3)	3	At assessment	565 501	535 476	461 406	*10^{6} *10^{6}
RCT3 Assessment 2006	NEA cod	Recruits (age 3)	3	At assessment	533	546		*10^{6}

[1] Based on prognosis estimate of capelin maturing biomass for October 1 2006, thereby allowing for an additional year.

[*] Numbers were calculated before the 2005 assessment (ICES, 2005), and have not been updated for the 2007 assessment.

[**] **Numbers were updated in July 2007.**

Table 6.4. Qualitative estimations of impact on of the ecosystem factors on some stocks in the Barents Sea for 2007.

Species	Stock parameters	Ecosystem parameters									Total expectation
		Temperature of water	Zooplankton biomass	Capelin biomass	Herring biomass	Polar cod biomass	Blue whiting biomass	Cod biomass	Harp seal abundance	Whales abundance	
NEA Cod	Abundance at age 0+	+	++	+	−	?	−	+ −	?	?	M
	Cannibalism	++	−	+	−	−	−	+	?	?	M
	Rate of growth	++	+ −	− −	++	− +	+	−	+ −	−	M
	Rate of maturation	+ −	+ −	− −	+	?	+	+ −	?	?	M
Capelin	Abundance at age 0+	+	++	− −	− −	−	−	−	?	?	L
	Natural mortality	++	− −	− −	+	−	+ −	+	+ −	++	H
	Rate of growth	++	+	++	−	−	−	+ −	?	?	H
	Rate of maturation	++	+	++	−	−	−	+ −	?	?	H

H – high, M – medium and L – low value of stock parameters in compare with long-term mean.
+ positive (++ strongly positive)) influence of ecosystem parameters on stock parameter;
+ − influence of ecosystem parameter on stock parameter without clear positive or negative effects;
− negative (-- strongly negative) influence of ecosystem parameters on stock parameter;
? knowledge are not available.

6.3.2 Long-term prediction

6.3.2.1 Effect of long-term changes in climate on cod abundance and distribution

Global Circulation Models (GCMs) predict significant warming around the globe under higher levels of greenhouse gases (IPCC, 2001). Although the amplitude of the warming varies according to the particular GCM used, they all show proportionately greater warming in the Sub-arctic and Arctic regions. Multi-model scenarios suggest 2-4ºC temperature increases in most regions occupied by cod by 2100, with a maximum of 6ºC in the Barents Sea. What will be the impact on the cod stocks? Coupling current knowledge about the impact of climate variability on Atlantic cod with predictions of future climate change Drinkwater (2005) made the following predictions. If temperature increased to 1 or 2ºC above present day values, NEA cod would benefit from increased recruitment. If temperature increased by 3ºC the stock of NEA cod as Norwegian coastal cod would not see any further change in recruitment. For a 4ºC temperature change, the Norwegian coastal cod stocks would begin to see declining recruitment while would level off. Results of the same analysis to other cod stocks in the North Atlantic show that anticipated warming would have more dramatic effect on many stocks (Figure 6.8). According such forecast warming by 3ºC would likely result in the disappearance of upwards of 5 cod stock in the NE Atlantic and declines in several 3 others.

Future warming in the Barents Sea will cause the cod to spread farther east and north. Cod will also spread northward along western Svalbard and NEA cod may even extend into the northern Kara Sea, if only to migrate there in summer. Earlier migration to the summer feeding and spawning areas will occur as well as a later return to the overwintering grounds.

In areas where seasonal ice will disappear, migration might cease altogether. Spawning would likely occur earlier with faster gonadal development, and the average age of maturity is expected to decrease. There will be higher growth rates and fish will be in better condition.

One should keep in mind, however, that such projections have not taken into account future fishing intensity. If fishing reduces present cod stocks to minimal levels, there may not be enough cod to expand and drive the predicted increased production, certainly not to the extent that could potentially occur given reduced fishing. Also, the expanding and increasing cod production may be reduced quickly through fishing, thereby limiting the production increase and the extent of the geographic expansion. The predictions of cod impacts will also depend on the changes to other parts of the ecosystem. These include changes to primary (phytoplankton growth) and secondary production (zooplankton growth) in the Barents Sea and, more specifically, the specific food for larval and juvenile cod – such as *Calanus finmarchicus* - and, for adults, food such as capelin.

6.3.2.2 Model analysis consequences of changes in marine mammals abundance for fish stock dynamics in the Barents Sea

Results from MULTSPEC simulations (Tjelmeland and Bogstad 1998) showed that the herring stock is much more sensitive to changes in the minke whale stock than changes in the harp seal stock. Because in the model development in the capelin stock is strongly determined by changes in the herring stock when the minke whale stock increases or decreases the capelin stock increases or decreases. Since herring is less sensitive to changes in the harp seal stock than to changes in the minke whale stock, and since predation on capelin from harp seals is high, an increase or decrease in the harp seal stock leads to a decrease or increase in the capelin stock. The cod stock will increase or decrease when marine mammals stocks decrease or increase. One interesting feature, which reflects the complexity of the system, is that there, would be large gains on average in the cod fishery by removing the seals than by removing the whales, despite the fact that whales eat more cod than seals do in the model runs. The explanation lies in the indirect effect through the herring-capelin-cod dynamics: Removing whales has a large effect on the herring stock, leading to strongly reduced capelin stock and thereby reduced cod stock growth, while removing harp seals would not have the similar indirect effect in model.

A tentative conclusion on likely effects of an increasing whale stock on important fish stocks is that the herring stock will be most heavily affected. An increasing harp seal stock will most heavily affect the capelin and cod stock.

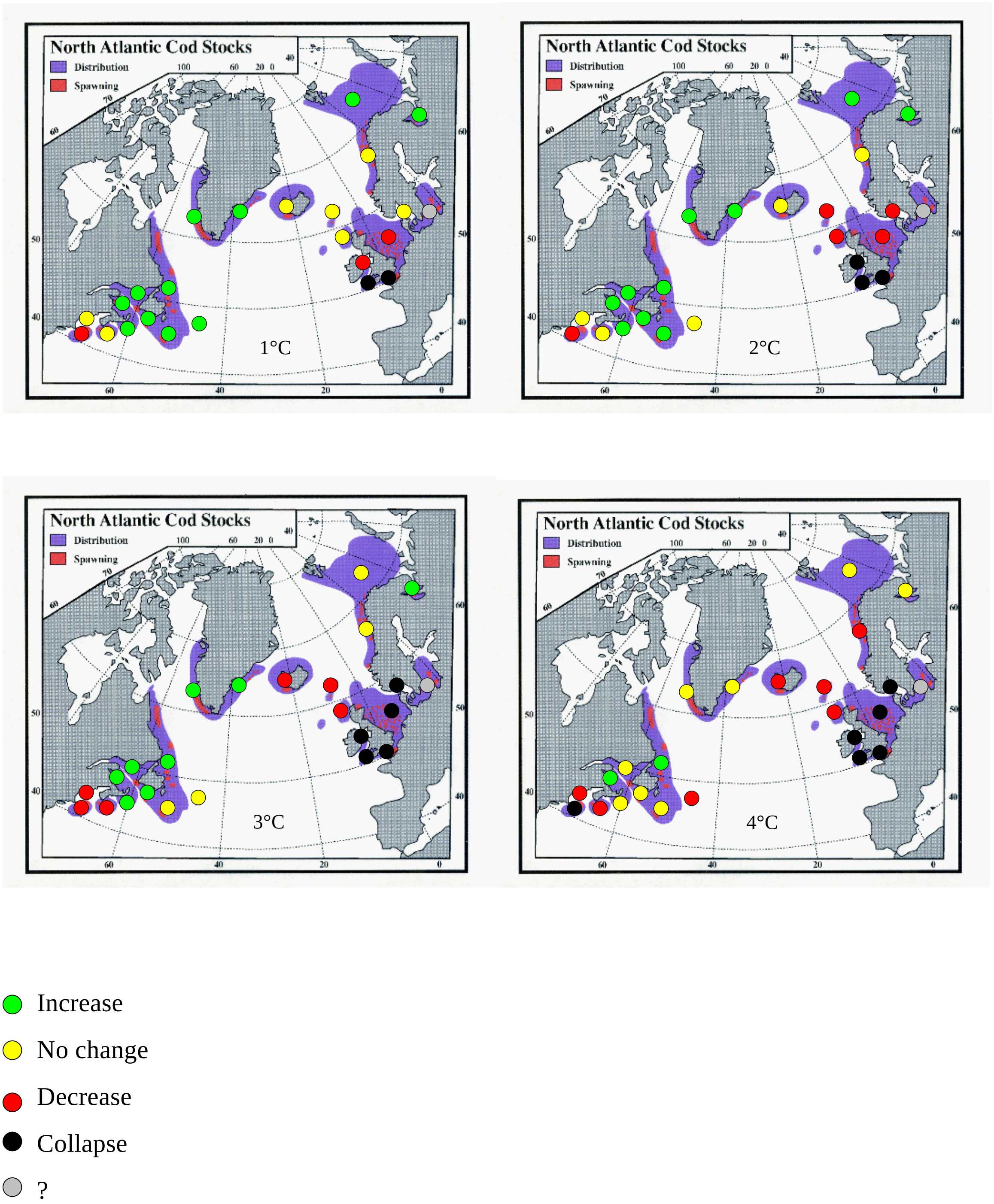


Figure 6.8. The expected changes in the abundance of the cod stocks with 1ºC, 2ºC, 3ºC and 4ºC temperature increases. The changes are relative to the previous figure, i.e. the changes at 2ºC are relative the abundances at 1ºC.

6.4 Optimization of harvesting strategy in an ecosystem context

6.4.1 Evaluation cod-capelin-herring multispecies harvesting control rules by Bifrost model

The harvesting control rule for present-day management of capelin is that the probability of the spawning stock being smaller than 200000 tones should be less than 5%. This is a precautionary consideration to ensure full benefit from very good recruitment conditions, but takes no account of what is the best management in the long-term ecosystem context.

Figure 6.9 shows the long-term yield of capelin as function of target spawning stock, showing a maximum long-term yield of about 0.275 million tonnes for a target spawning stock of 0.4 million tonnes. In these simulations the F-values of cod by age have been kept at the mean of the 3 last year’s (2003-2005) actual F-values. Increasing the F-value of cod will increase the long-term yield of capelin. The harvesting control rule for herring has been kept at F = 0.125, which is used at present and which keeps a fairly high herring stock.

Figure 6.10 shows the long-term yield of capelin as function of target spawning stock with an F-value for herring of 1.0, which leads to a nearly vanishing herring stock. Without herring the long-term mean capelin yield is more than 0.7 million tonnes and the optimal target spawning stock must be increased from 0.4 to 0.6 million tonnes.

In Bifrost, the cod stock is affected by the size of the capelin stock through individual growth being dependent on the capelin stock and through capelin shielding the young cod from cannibalism. The latter effect is dominating. Figure 6.11and Figure 6.12 show the long-term mean yield of cod as function of F relative to the mean of the F-value during the three last years for the two scenarios above. The optimal F is markedly lower than the current F and the maximum long-term yield increases by more than 100000 tonnes when the herring vanishes.

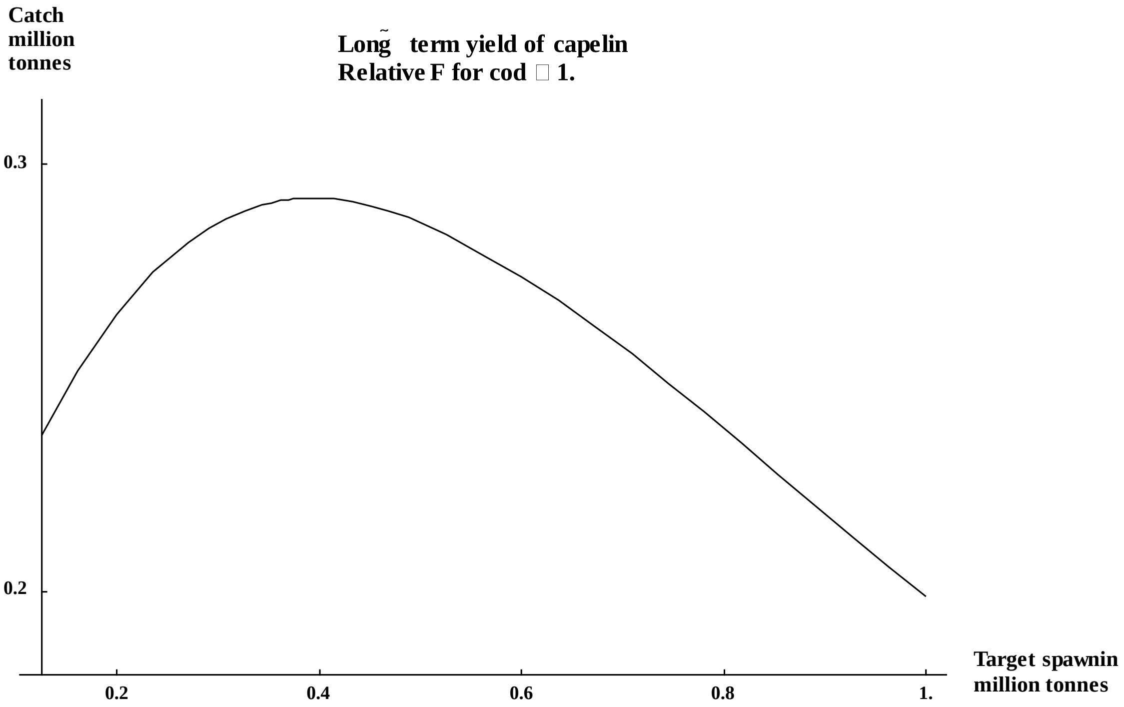


Figure 6.9. Long-term mean yield of capelin from Bifrost as function of target spawning stock for F = 0.125 for herring and a cod F-value by age equal to the mean of 2003-2005.

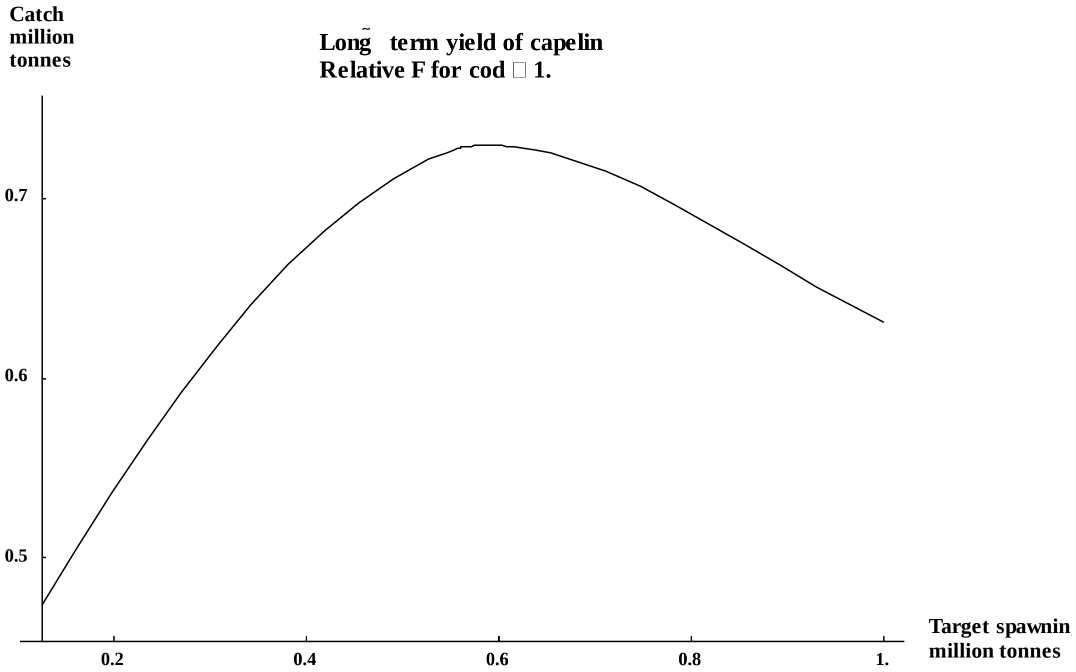


Figure 6.10. Long-term mean yield of capelin from Bifrost as function of target spawning stock for F = 1.0 for herring and a cod F-value by age equal to the mean of 2003-2005.

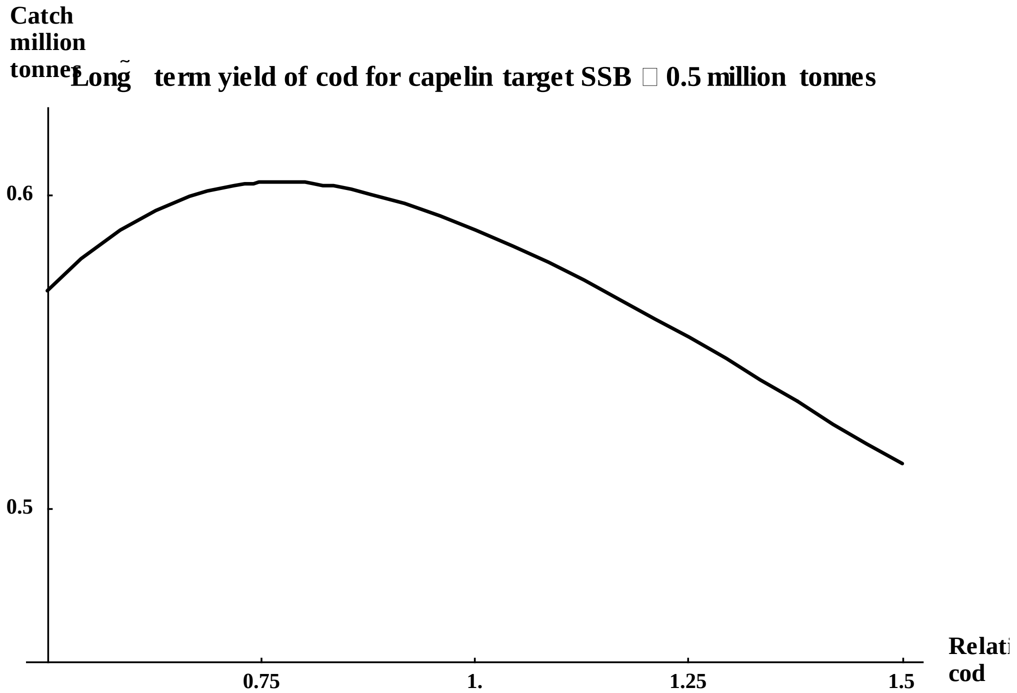


Figure 6.11. Long-term mean yield of cod from Bifrost as function of F relative to the mean of F by age in 2003-2005 when the target SSB for capelin is 0.5 million tonnes and F for herring is 0.125.

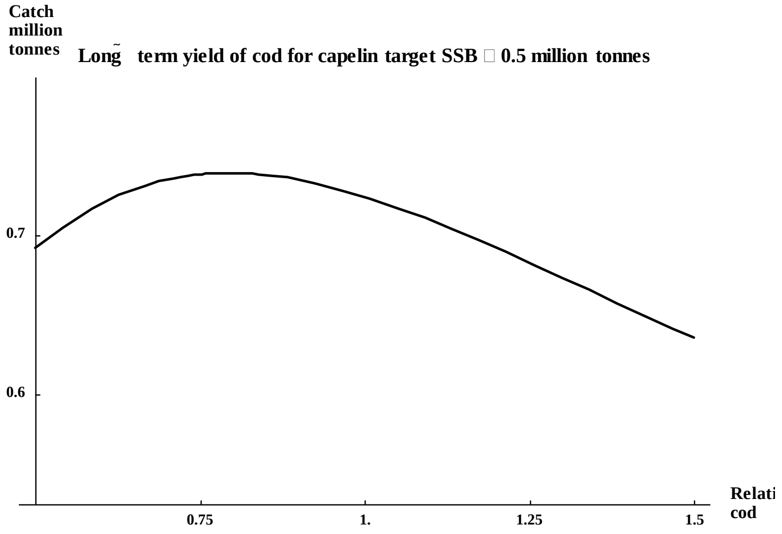


Figure 6.12. Long-term mean yield of cod from Bifrost as function of F relative to the mean of F by age in 2003-2005 when the target SSB for capelin is 0.5 million tonnes and F for herring is 1.0.

6.4.2 Potential EcoCod for ecosystem evaluation of harvest control rules for cod

The EcoCod model is designed for evaluating harvest control rules for Northeast arctic cod with temperature and capelin abundance dependent growth, capelin dependent skipped spawning, age dependent malformation of eggs and length dependent fecundity. The simulations in the present stage of the model development serve to elucidate the direction and magnitude of different system effects not included in the present management of the cod stock, with respect to what might be our perception of maximum long-term yield and associated HCR. During the present simulations the herring stock is kept at constant value only and the present cod recruitment model has not captured temperature dependence. This is used to explore the effect of different levels of the herring stock leading to different levels of the capelin stock, which again influences cod growth, cod maturation and the amount of skipped spawning. One should, however, bear in mind that a constant value for the herring abundance is quite unrealistic. In a later stage of the project the herring scenario will be based on stochastic prognostic simulations with the model used at present for assessment of Norwegian spring spawning herring - SeaStar - (Røttingen and Tjelmeland 2003, Tjelmeland and Lindstrøm 2005) and the temperature scenarios will be based on autocorrelation preserving stochastic prognostic simulations based on data from the Kola section (Samuel Subbey, pers. comm.).

When the capelin stock is included in the cannibalism model the results are sensitive to the level of the capelin stock, which are determined by the level of the herring stock. Including skipped spawning decreases the optimal F and increases the long-term yield. The level of the capelin stock does not influence the effect of skipped spawning unless skipped spawning is applied to all age groups and the critical condition is increased, in which case both the optimal F-value and the associated long-term yield are increased. Including the model for growth in weight at age leads to a marked decrease of long-term yield and to a marked increase in optimal F-value. It is seen that the growth model is sensitive to both the amount of capelin and to the temperature. The influences from temperature and herring are substantial, first of all probably through the model for pre-spawning cannibalism, which is an effect that should be investigated thoroughly during the remaining period of the project.

From the present results it seems that the single most important process to investigate further is the pre-spawning cannibalism and the associated model for capelin. Results of present simulation by EcoCod revealed that F must be decreased from the present value of 0.40 in order to achieve maximum long-term yield. Because of its preliminary nature, the current study does not give a definite answer about the magnitude of this reduction in F that can be is regarded as recommendation to management implementation. This will be the issue for future study.

7 Levels and impact of pollution on the ecosystem

By S. Boitsov, J. Klungsøyr, N. F. Plotitsina and A. Yu. Zhilin

7.1 Overview

The Barents Sea is considered a relatively clean environment, not much affected by inputs of contaminants from human activities, and the contamination level is in general lower than in more temperated areas. However, natural sources, long-range transport and accidental releases from local activities may all contribute to increased contamination levels in the marine environment. Organic contaminants are often poorly soluble in water. Thus, they are easily absorbed by organic material like plankton, and may thereby lead to uptake by marine biota. Certain contaminants may be metabolized and excreted by higher organisms like fish without causing much harm, assuming the concentrations are below the threshold values for negative biological effects, while others may not be metabolized and will remain in the organism. In this case, most organic contaminants like PCBs will accumulate in the liver, while trace amounts may also be found in muscle tissues, which may later be consumed by humans. Bioaccumulation in the marine food chains may also occur, leading to aggregation of contaminants in organisms at the top of the food chain.

A large part of contaminants entering the marine environment will, depending on their chemical and physical properties, get adsorbed to organic particles and end up in sediments, which may act as a sink for contaminants. Among these, polyaromatic hydrocarbons (PAH) play a significant role in the Barents Sea where hydrocarbon resources are present. PAH levels may thus be increased due to natural processes such as erosion of coal-bearing bedrock at Svalbard (Spitsbergen) or due to possible leakage of oil and gas from the seabed. Anthropogenic sources of hydrocarbons may thus play a less important role in the Barents Sea. However, the increasing oil exploration activities require regular monitoring of contamination levels. With regard to other types of contaminants, in particular persistent organic pollutants (POPs) such as PCBs, DDT and others, most of which have only anthropogenic sources, long-range transport (both by air and with sea currents) may result in increased levels in the Barents Sea. Monitoring the levels of these contaminants is necessary to document the situation and to control the efficiency of international measures taken to reduce the inputs of these contaminants to the environment.

7.2 Sampling

The analyses of the concentration levels of the contaminants in some important commercial species of the Barents Sea fish were carried out on samples collected during the cruises of the fishing vessel “Demyansk” in the Russian part of the Barents Sea 2004 and 2005. Figure 7.1 shows the sampling areas. A total of 70 samples were analyzed (35 muscles samples and 35 liver samples).

The analyses of the contaminants in bottom sediments from the area South and East of Svalbard in the Barents Sea were carried out on samples collected during the cruise with RV “Fridtjof Nansen” in 2005. A total of 38 samples were analyzed.

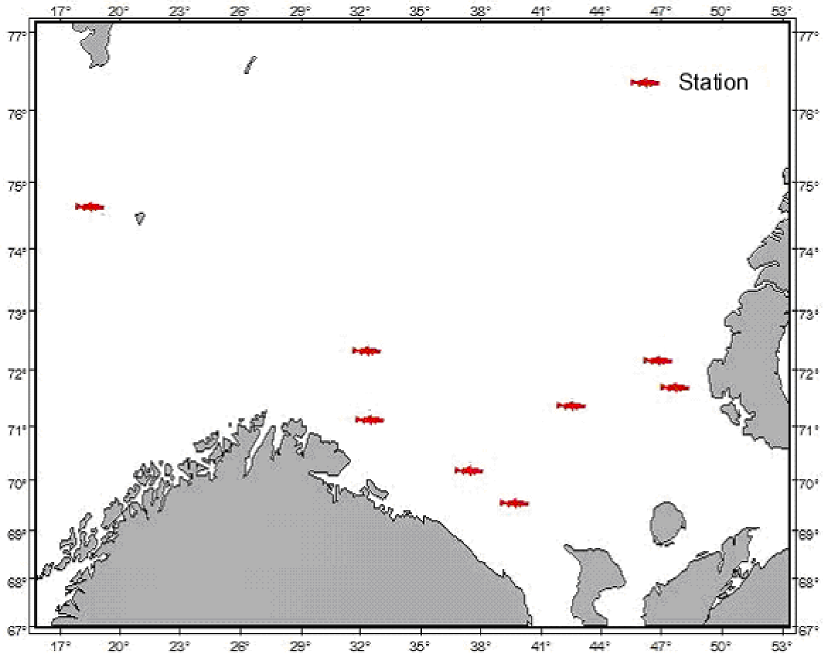


Figure 7.1. Location of fish sampling stations (F/V «Demyansk» cruises, September-December 2004 and May-August 2005).

In 2003-2004, scientific cruises with R/V Johan Hjort (2003) and Håkon Mosby (2004) were carried out by IMR in the Norwegian part of the Barents Sea. One of the purposes of the cruises was to collect samples of sediments to get new information about the levels of contaminants like oil (THC) and polyaromatic hydrocarbons (PAH).

In 2003, surface sediment samples were collected at 29 stations in the western part of the Barents Sea, between ca. 70^o and 77^o North and 20^o and 40^o East (Figure 7.2). In 2004, sediment cores were collected at 45 locations along 5 transects each going from the Barents Sea shelf and westwards across the continental slope to a depth of 1500 m (Figure 7.2).

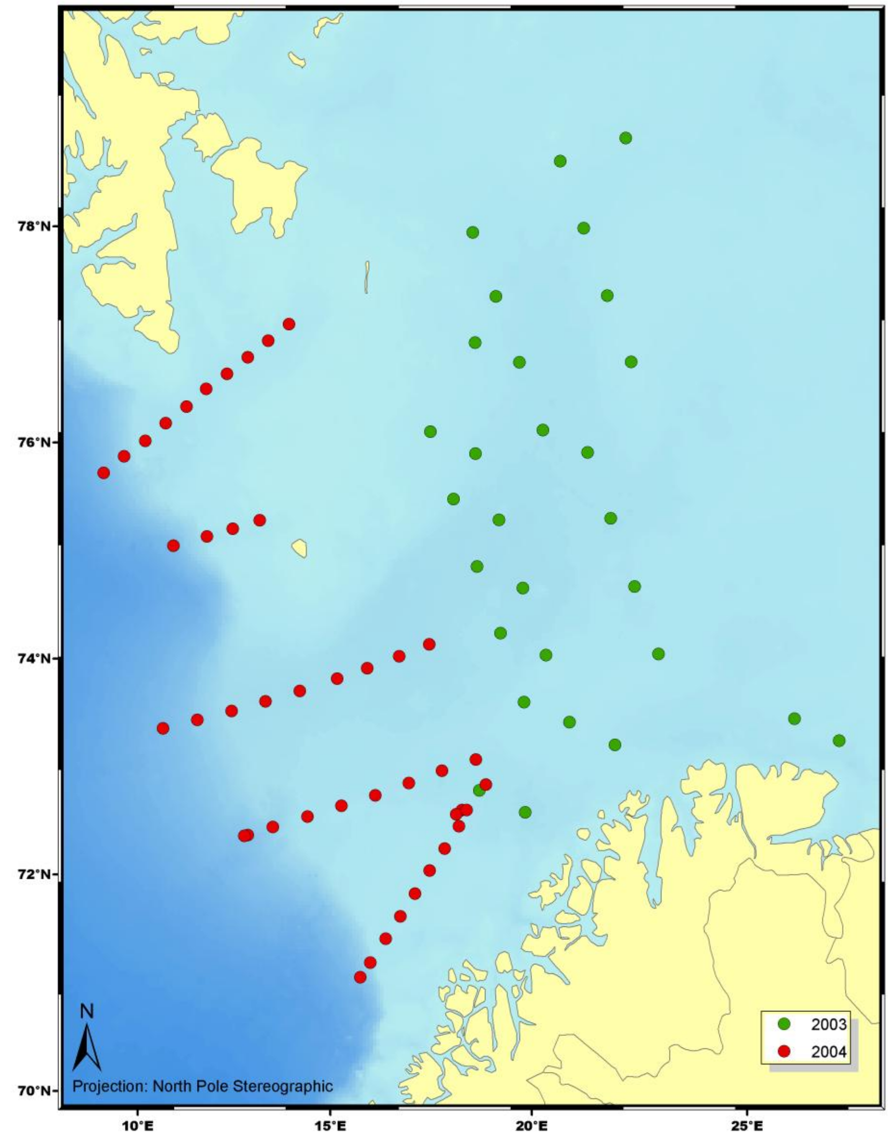


Figure 7.2. Sediment sampling stations of the 2003 and 2004 IMR cruises.

7.3 Contaminants in fish

Figure 7.3 show the content of aliphatic hydrocarbons (n- paraffin C_{10}-C_{32}) and polyaromatic hydrocarbons (PAH) (sum 16 compounds, EPA protocol 8310) in fish from the Barents Sea.

Concentrations of benz[a]pyrene in muscles of the studied fish was below the detection limit of the applied method of analysis. The concentration of PAH in the fish liver in most cases was higher than in muscles as the liver is an accumulating organ. Among individual PAH, phenanthrene was found at highest concentrations in fish muscle, in liver it was naphthalene and benzo(g,h,i)perylene.

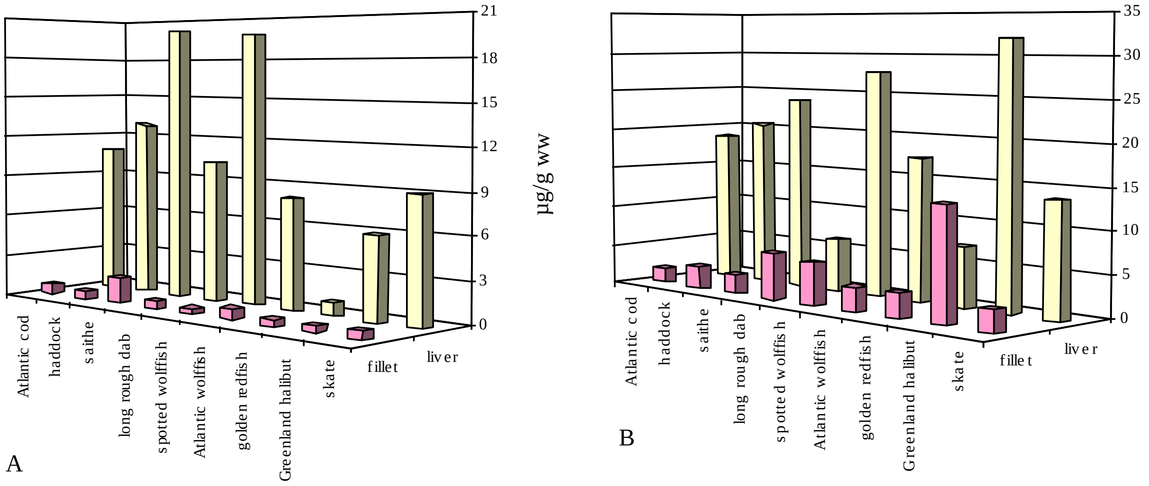


Figure 7.3. The concentrations of n- paraffin (A) and sum PAH (B) in fish.

Combined concentrations of organochlorine pesticides and polychlorinated biphenyls in fish muscles from the Barents Sea did not exceed the permitted levels approved by the Russian sanitary code for food raw products and provision. Hexachlorocyclohexane, hexachlorobenzene and chlordanes residue in muscles of the studied fish did not exceed 2 ng/g wet weight. Among pesticides found in muscles of studied fish, DDT and its metabolites were dominating. Tetra-, penta- and hexachlorobiphenyls (congeners 52, 118, 138, 153) constituted 90 % of the total PCB in fish muscle. The higher content of p,p’-DDE in the muscles of fish compared with other isomers, indicates DDT transformation over a long-time.

Data on concentrations of organochlorine pesticides and PCB in the liver of fish from the Barents Sea are presented in Figure 7.4. In fish liver, DDT and its metabolites were dominating, with the isomers of chlordane, hexachlorocyclohexane and hexachlorobenzene following. Composition of individual PCB in the liver of the studied fish from the Barents Sea had a predominating number of the congeners 153, 138, 118, which may indicate that commercial mixtures of polychlorobiphenyls of Aroclor type (Russian analogues – sovol and sovtol) was an important source.

Iron was the dominating metal in fish muscles. The concentration of nickel, chromium, cobalt, lead and cadmium in the muscles of all fish studied was below the detection limits of the applied analytical method. Concentrations of copper, zinc and mercury in the muscles of the fish studied varied in a very narrow interval, and corresponded to natural background levels. Concentrations of cadmium in the liver of all fish studied did not exceed the permitted level of 0,7 µg/g wet weight, established by sanitary standards for the liver of fish. An exception was the liver of Atlantic wolfish, in which the concentration of cadmium exceeded the standard twice. The content of arsenic in individual samples of cod, sand-dab, wolfish, haddock, thorny skate muscles exceeded the established standard of 5,0 µg/g wet weight.

It was found that n- paraffins were predominating in the muscles and liver of the fish, with a pattern characteristic of saturated aliphatic hydrocarbons of biogenic origin. The results from the present investigation indicate a low level of PAH in the Barents Sea fish. The concentration of chlorinated hydrocarbons and high metals such as lead, cadmium and mercury in the muscles and liver of fish was well below the allowed levels established by sanitary standards for fish and sea products. The concentration of arsenic in the muscles of different species of fish exceeded the established standard.

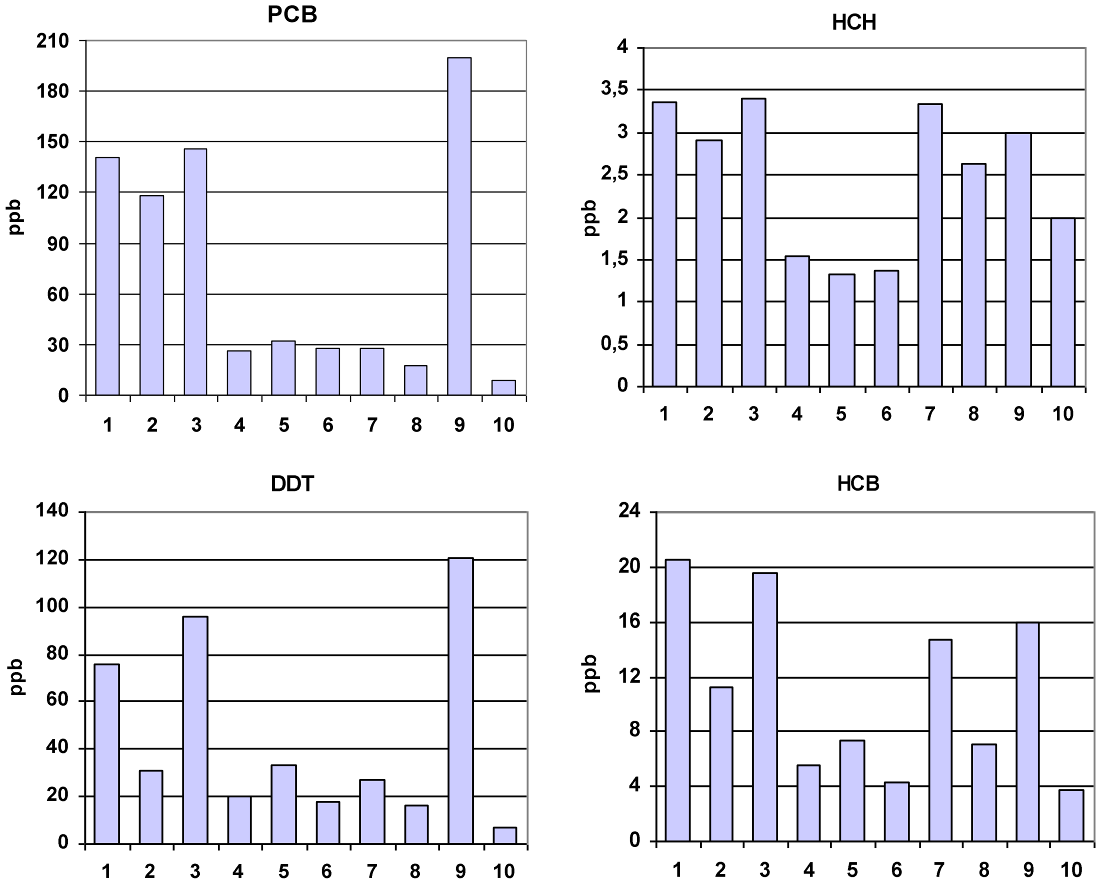


Figure 7.4. Average concentrations (ng/g wet weight) of PCBs (sum of CB congeners no 28, 52, 101, 118, 138, 153, 180), HCHs (sum alpha-, gamma-HCH), DDTs (sum p,p,-DDE, o,p,-DDD, p,p,-DDD, o,p,-DDT, p,p,-DDT), HCB in liver of Atlantic cod (Gadus morhua) (1), haddock (Melanogrammus aeglefinus) (2), saithe (Pollachius virens) (3), long rough dab (Hippoglossoides platessoides) (4), spotted wolffish (Anarchichas minor) (5), Atlantic wolffish (Anarchichas lupus) (6), golden redfish (Sebastes marinus) (7), Greenland halibut (Reinhardtius hippoglossoides) (8), skate (Raja radiata) (9) and polar cod (Boreogadus saida) (10).

7.4 Contaminants in sediments

Distribution of aliphatic hydrocarbons (n- paraffin C_{10}-C_{32}) in the upper layer of the bottom sediments from Svalbard area is presented in Figure 7.5. Aliphatic hydrocarbons of biogenic origin dominated, their contents varying from 1 to 240 µg/g dry weight. This was below the technogenic background level characteristic for the upper layer of bottom sediments from the Western Arctic shelf.

The distribution of polyaromatic hydrocarbons (PAH) in the bottom sediments from the Barents Sea investigated areas is presented in Figure 7.5. Maximum PAH levels (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 % total PAH concentrations in the bottom sediment 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 show the increased concentrations of PAH in bottom sediments from the coastal areas of Spitsbergen in comparison with other parts of the Barents Sea. In accordance with the classification of contaminant levels in marine bottom sediments adopted by SFT (Norwegian Pollution Control Authority), the concentration of PAH and benz(a)pyrene in bottom sediments in the investigated areas adjacent to Spitsbergen archipelago corresponds to levels of moderate contaminantion.

Figure 7.6 shows the distribution of organochlorine compounds in bottom sediments in the investigated areas of the Barents Sea near Svalbard. Sum concentraton of hexachlorcyclohexane (HCH) in bottom sediments in the investigated areas of the Barents Sea varied from 0,27 to 2,26 ng/g dry weight (Figure 7.6 A). The increase in the relative concentration of the more stable isomer α- HCH in comparison with γ-HCH (α-HCH/ γ-HCH <1) indicates a long lasting inflow of hexachlorocyclohexane into the marine environment. In bottom sediments from the studied areas, only hexachlorobenzene residues are defined (Figure 7.6 B); among chlordane isomers (Figure 7.6 C) *cis*-chlordane, *trans*-chlordane and *trans*-nonachlor were represented in minor amounts. The concentration of DDT (sum of o,p’–DDT, p,p’–DDT, o,p’-DDD, p,p’-DDD, p,p’–DDD) in bottom sediments from the studied areas varied from 0,36 to 1,79 ng/g dry weight (Figure 7.6 D). The contents of p,p’-DDE isomer in bottom sediments exceeded the contents of p,p’–DDT isomer at all investigated stations and indicated a prolonged transformation process of DDT into more stable metabolites. In accordance with the classification of contaminant levels in marine bottom sediments adopted by SFT, investigated bottom sediments from the Barents Sea should be categorized as “moderately contaminated” by DDT. Sum content of polychlorobiphenyls (PCB) (sum of CB congeners 28, 52, 101, 118, 138, 153, 180) in bottom sediments varied from 0,7 to 5,12 ng/ g dry weight (Figure 7.6 E). Among individual PCB compounds in the upper layer of bottom sediments, the congeners 52, 118, 138, 153 predominated in the commercial mix proportion of Aroclor type (Russian analogues – sovol and sovtol). According to the criteria of contaminants in the marine bottom sediments and coastal waters adopted in Norway, sum contents of 7 PCB congeners nr. 28, 52, 101, 118, 138, 153, 180 in bottom sediments from the studied areas corresponded to the technogenic background level (<5ng/g dry weight).

Distribution of micro- and macroelements in the upper layer of the Barents Sea bottom sediments nearby Svalbard is shown in Figure 7.7. According to the criteria of contaminants in the marine sediments adopted in Norway, the most part of investigated bottom sediments in the Barents Sea can be categorized as “moderately contaminated” by nickel and chromium. Concentrations of other metals corresponded to natural background levels.

The results confirm a low level of contamination in bottom sediments from the investigated areas of the Barents Sea.

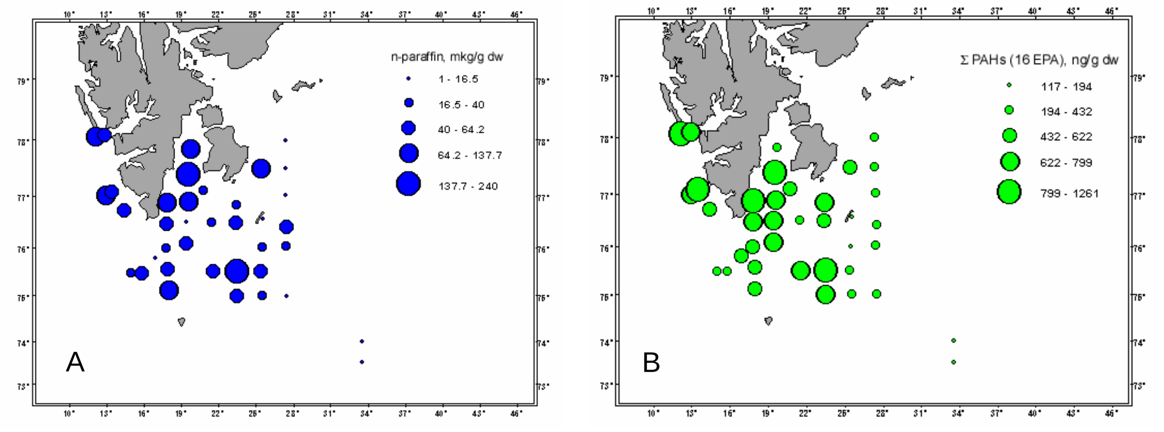


Figure 7.5. Contents of n-paraffins (A) and ∑PAHs (B) in bottom sediments.

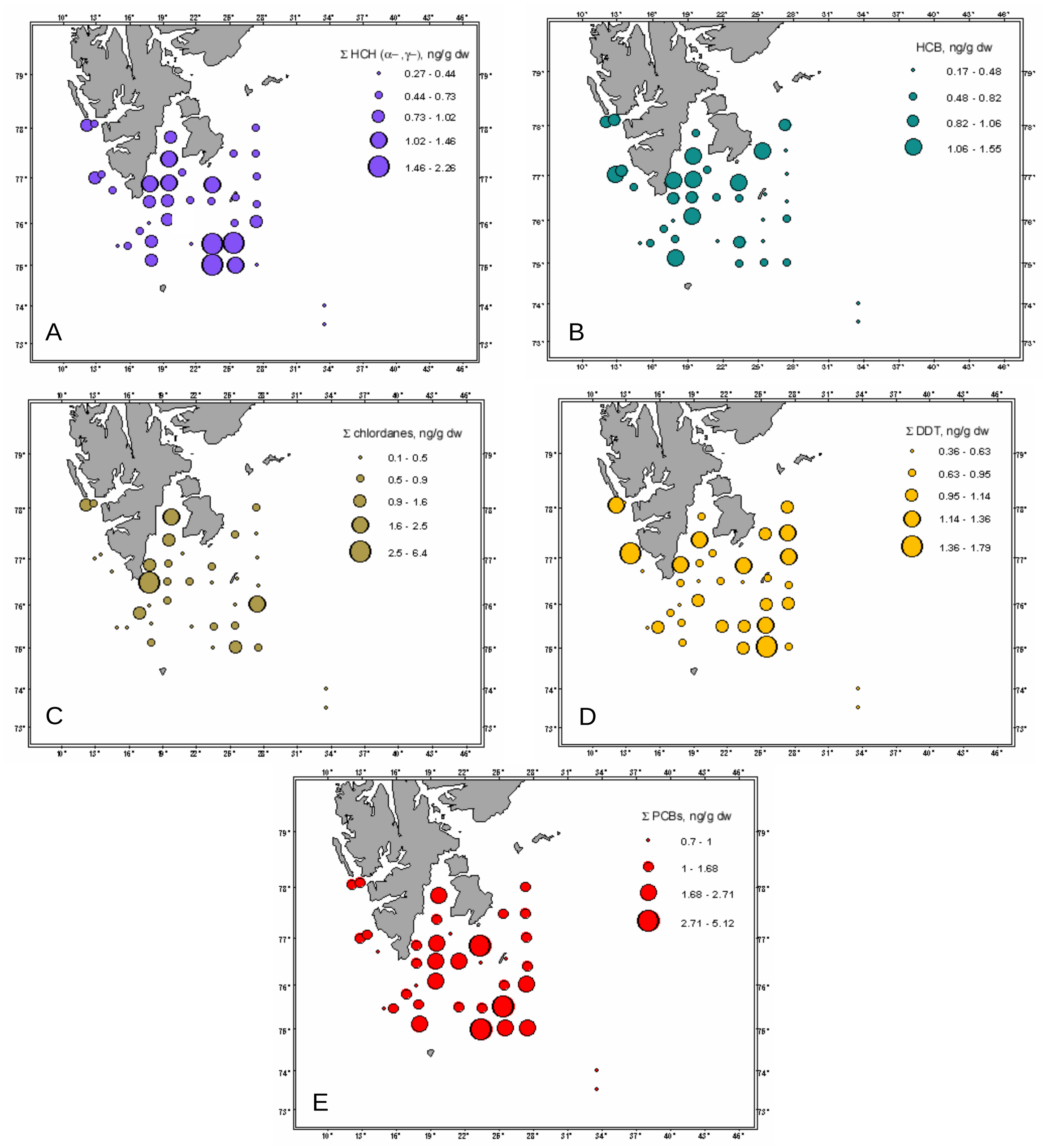


Figure 7.6. Contents of hexachlorocyclohexane (A), hexachlorobenzene (B), chlordanes (C),DDTs (D), PCBs (E) in bottom sediments.

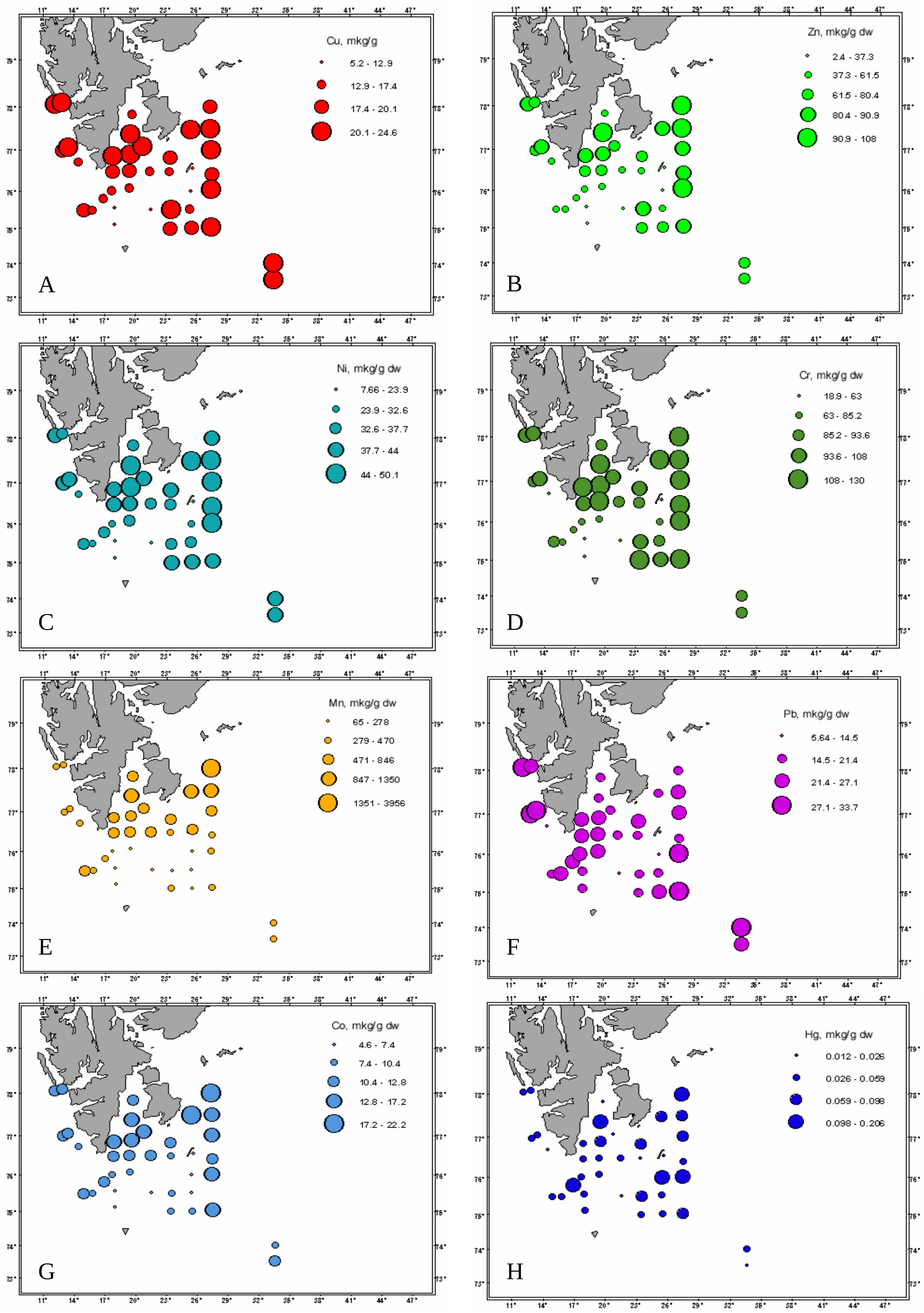


Figure 7.7. Contents of copper (A), zinc (B), nickel (C), chromium (D), manganese (E), lead (F), cobalt (G), mercury (H) in bottom sediments.

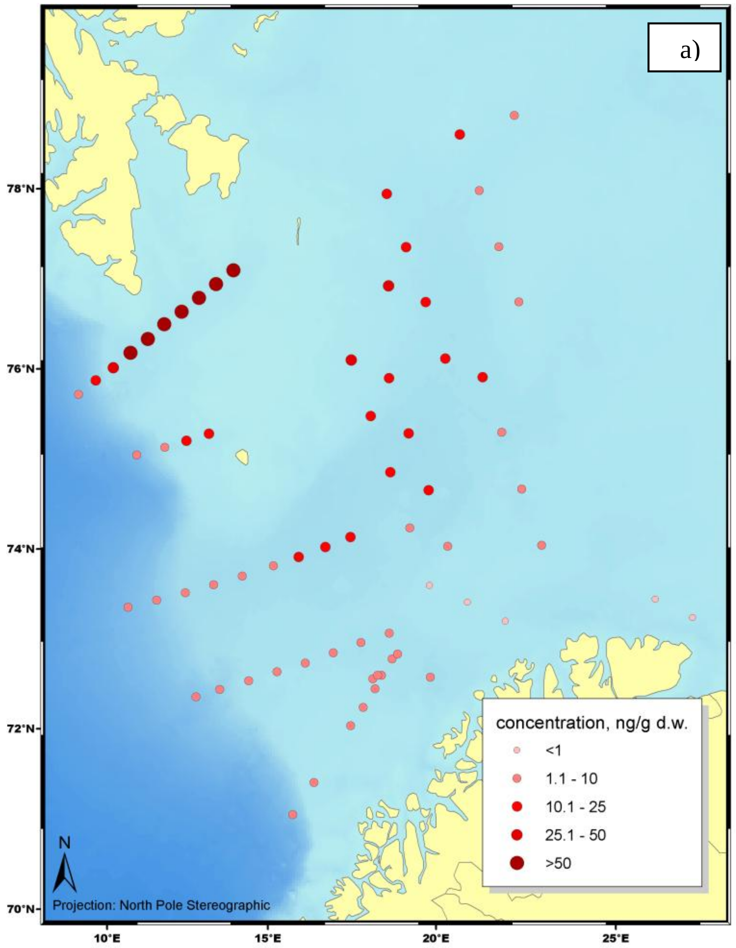
For 2004 samples collected by IMR throughout the Barents Sea, levels of PAHs vary from location to location between 37.42 ng/g to 1356.5 ng/g for the sum of 20 individual components analysed in surface sediments. The large difference between various locations may indicate a difference in inputs of PAHs in different areas, which results in differences in their deposition, or influence of local sources such as natural seepages of oil or other organic fossils. The mean values for sum of 20 PAHs in the Barents Sea have been measured at 414 ng/g in the 2004 investigation.

The highest concentrations of benzo[a]pyrene are observed in sediments at stations 30 and 32. The levels of benzo[a]pyrene at all stations of the 2004 cruise remained within the limits of insignificant-or-little contamination (below 10 ng/g dry weight) or moderate contamination (10 to 50 ng/g dry weight) by classification of the Norwegian Pollution Authority.

At all stations, alkylated naphthalenes heavily predominated over the parent compound, naphthalene. Alkylated phenanthrenes predominated at all stations, except station 9 of 2004 cruise where the amounts of the parent compound were comparable to those of its alkylated homologues and exceeding the amount of C1-homologues. For dibenzothiophenes, the same was observed at stations 9, 43 and 45, alkylated compounds predominating over the parent compound at all other stations. This indicates the petrogenic origin of PAHs in the studied areas.

Maps with PAH levels in surface sediments for a few representative compounds are shown in Figure 7.8. The levels of individual compounds exceed 50 ng/g at 21 stations (stt. 12 and 16-35) and exceed 100 ng/g at 9 stations (stt. 22 and 28-25), reaching 236 ng/g for phenanthrene at station 29. Geographically, the highest levels of PAH in surface sediments are observed close to Svalbard, which may be an indication of the natural sources present in that region. Svalbard is the area with large coal reservoirs, where coal-mining activities have occurred for decades. Also some oil and gas activities have taken place in this region since 1990-s. Levels in central Barents Sea and close to the Norwegian coast are low, although an increase is observed for some components in the Eastern part of the transects investigated.

Trends similar to 2004 data are observed in 2003 data. Maps with PAH levels for a few representative compounds are shown in Figure 7.8. The mean values for sum of 20 PAHs in the Barents Sea have been measured at 510 ng/g in 2003. As in 2004, highest levels are observed in the north of the sampled area, at stations closest to Svalbard; relatively high levels (above 50 ng/g dry weight) are observed at the majority of stations in the open sea areas for some high molecular components, particularly for perylene, a compound of biogenic origin. The lowest values are observed at stations close to the coastal areas. The levels of benzo[a]pyrene at most stations of the 2003 cruise remained within the limits of insignificant-or-little contamination (below 10 ng/g dry weight) or moderate contamination (10 to 50 ng/g dry weight) by classification of the Norwegian Pollution Authority (SFT 1997), slightly exceeding 50 ng/g d.w. at stations 673 and 677 only and thus falling into the “marked contamination” category at these stations. This classification, however, has been developed for evaluating anthropogenic contaminations in fjords and coastal waters, and is only mentioned here for comparison.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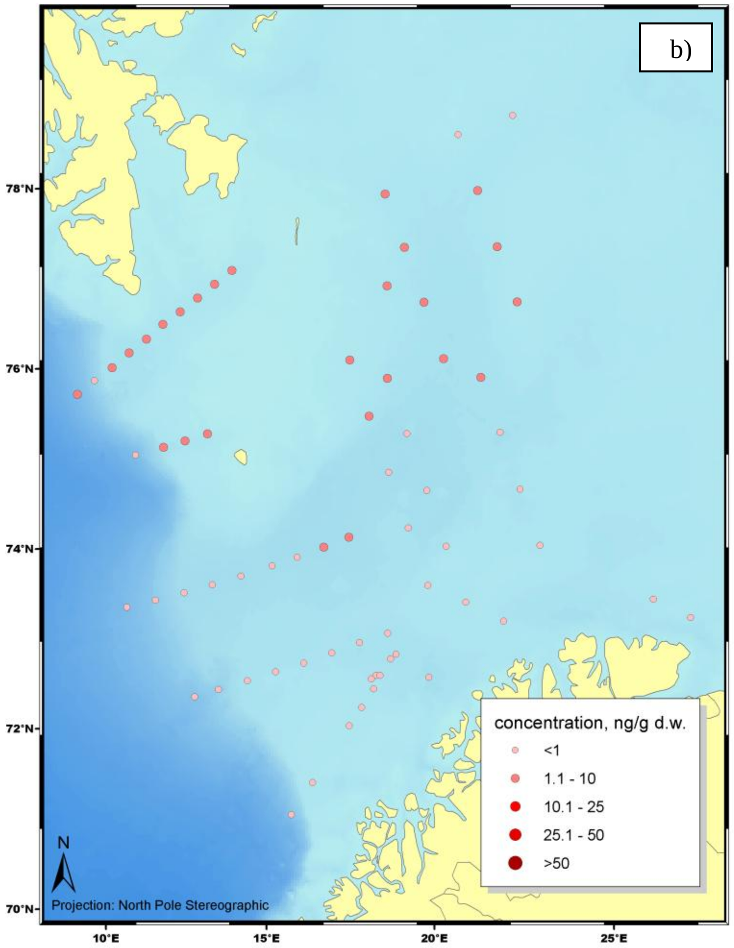
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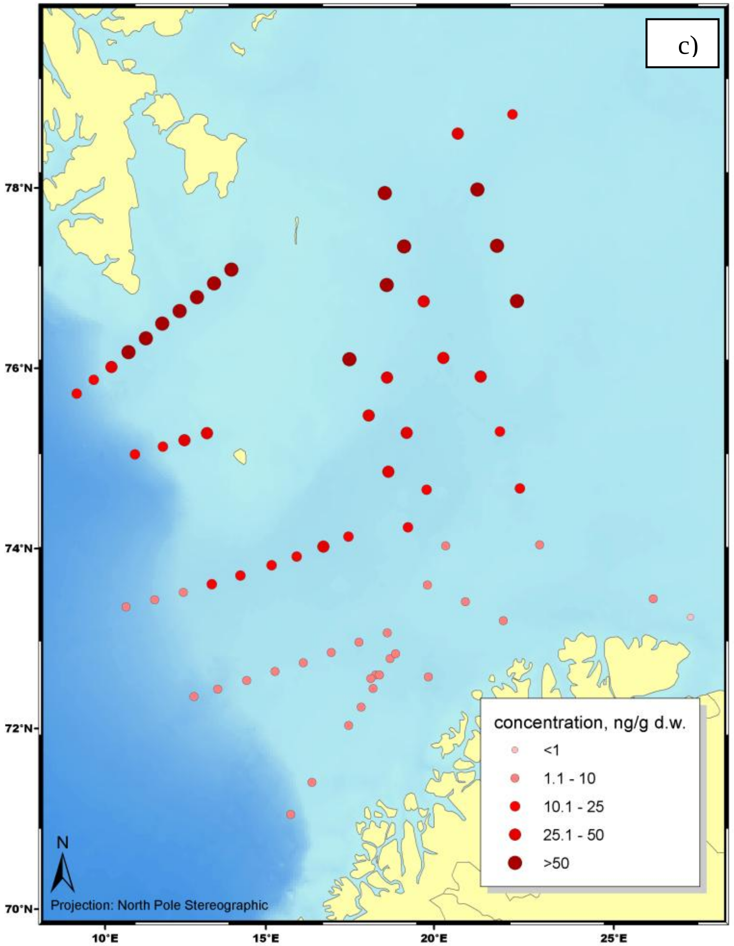
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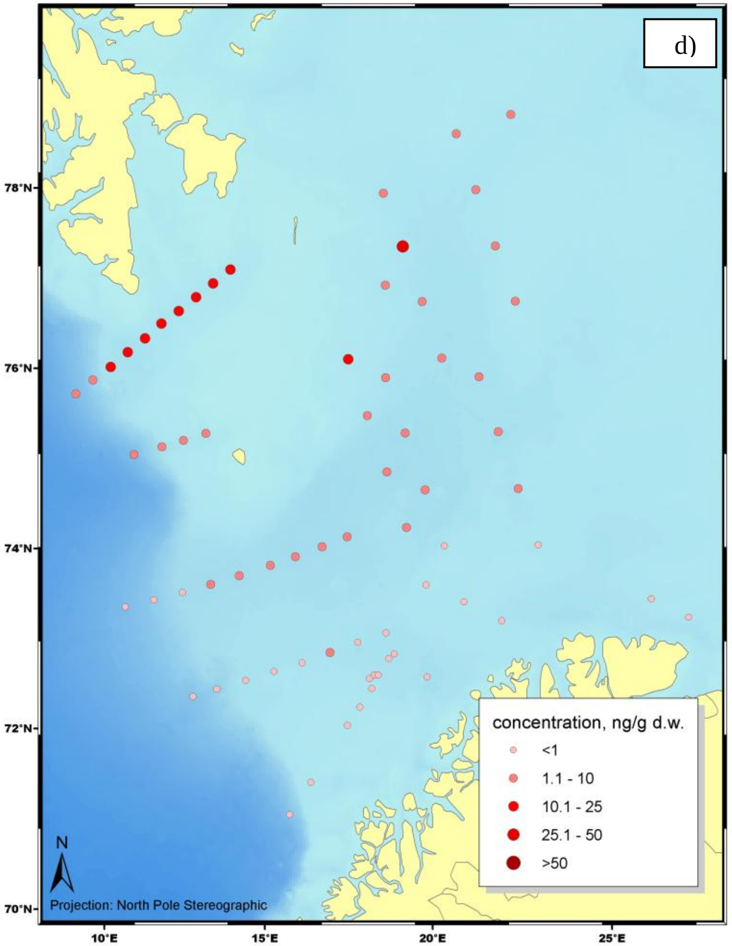
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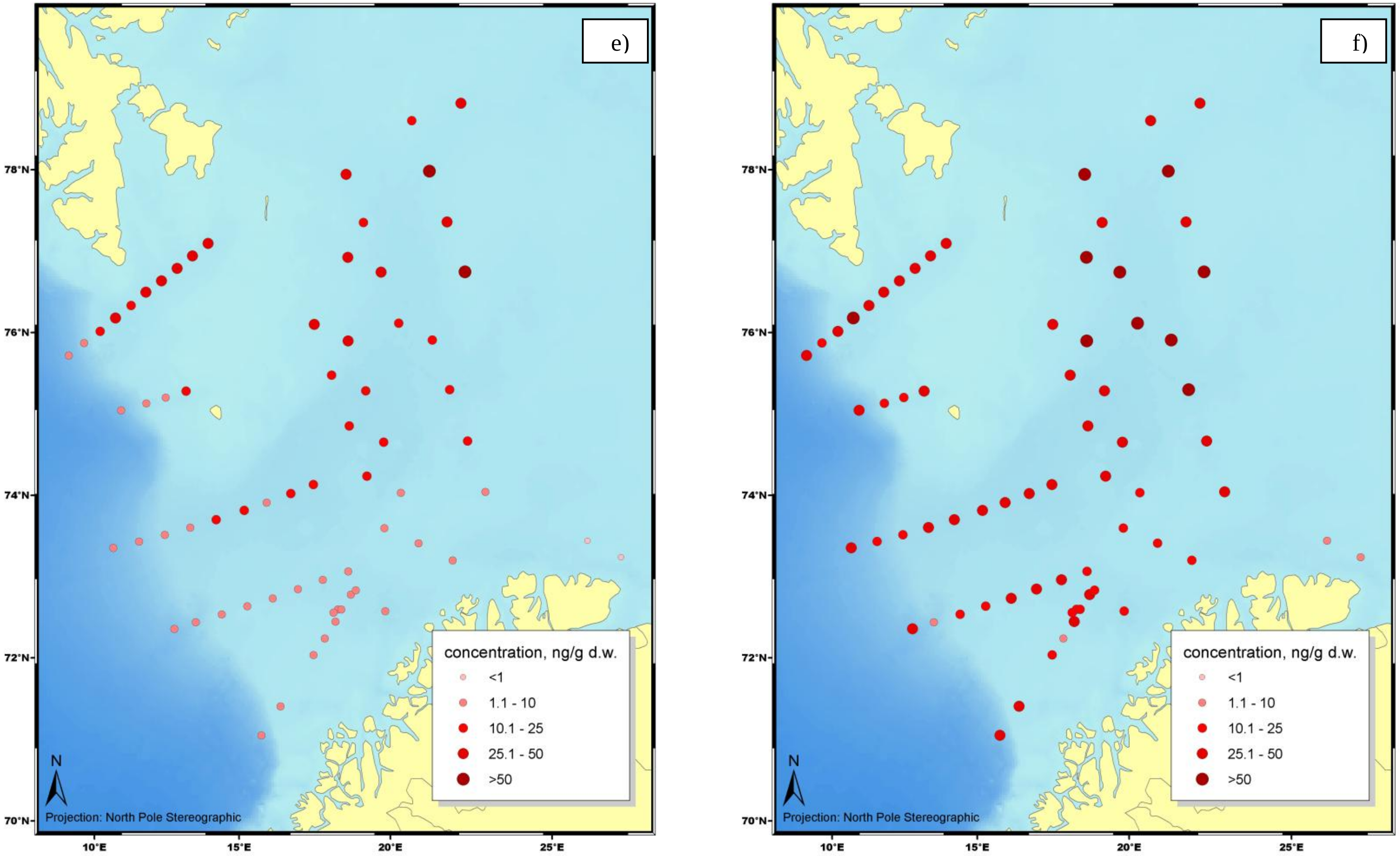

Figure 7.8. Maps of levels of selected PAH in surface sediments at various stations from IMR cruises in 2003 and 2004: a) naphthalene; b) anthracene; c) fluoranthene; d) dibenzothiophene; e) benzo[a]pyrene; f) indeno[1,2,3-c,d]pyrene.

Levels of total hydrocarbons (THC) measured in surface sediments are presented in Figure 7.9. The levels vary much from station to station, generally lying in ppm range both for 2003 and 2004 samples. The highest levels, observed for 2004 samples at stations 26-33 in the vicinity of Svalbard, are in the range of 50-70 µg/g. Most other stations show much lower values below 20 µg/g.

The Barents Sea remains a clean environment only weakly influenced by human activities. Local sources of natural origin contribute to elevated PAH levels in sediments in certain areas, in particular close to Svalbard. In the remainder of the studied area, the observed PAH levels are mostly due to complex sedimentation processes and long-range transport.

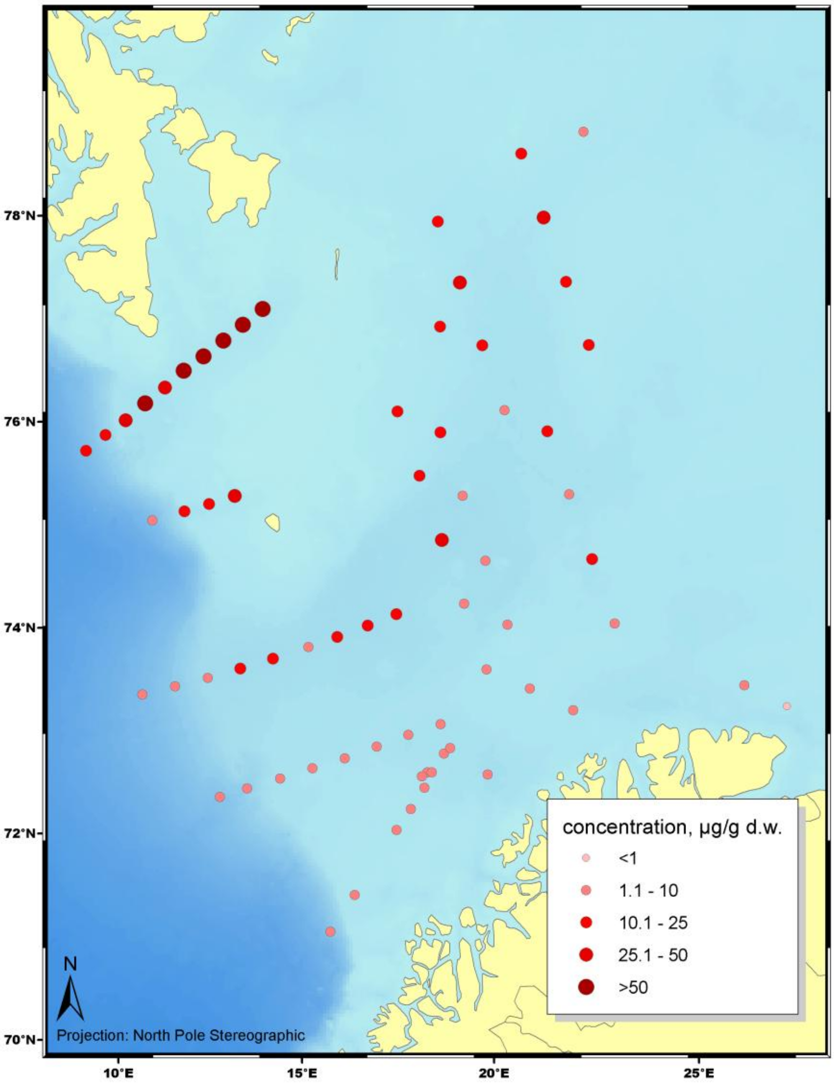

Figure 7.9. Maps of total hydrocarbon (THC) levels in surface sediments (0-1 cm) at various stations from the cruises in 2003 and 2004.

8 Risk on the ecosystem

By E. Olsen, O. V. Titov and M. A. Novikov

Integrated management of all human activities is an underlying principle in ecosystem-based management. Traditionally sector-based management has focused on the sector wise impacts, and fishing having been the most important and far-reaching human activity in the ecosystem has been given most of the attention and analyses of impacts and risks. Effective ecosystem-based management demands that we understand the risks associated with all other human activities in the Barents Sea. This is becoming increasingly more important as oil- and gas industry are starting to develop new off-shore fields in the Barents Sea, and the transport of oil and gas from the region has increased several times in the last 5 years.

This chapter gives a brief overview of the risks posed by the non-fishing human activities in the Barents Sea. Risk is traditionally defined as **Risk=likelihood×consequence**, but can be expanded to include costs (economic damage): **R_E=Risk×DamageCost** (Binenko and Berkovits, 2006)**.** In this chapter we will discuss risk related to the following fields:

- Hydrocarbon extraction (exploratory drilling, production, platforms etc)
- Transport of raw and refined hydrocrabon products and the handling of cargo
- Invasion of alien organisms

8.1 Hydrocarbon extraction

The Barents Sea is 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 will increase in the future as large oil, and especially gas, fields are being set in production. In Russia there are plans for the development Stochkman, a large gas-field west of Novaja Semlja. The environmental risks of oil and gas development in the region had been evaluated several times, and is a key environmental question facing the region. The key risk debated is the risk of an accidental oil-spill during exploration or production. The consequences of such a spill will be similar to a spill from a tanker accident, but the probabilities are much lower, and still speculative as there currently is no off-shore oil-field in production in the Barents sea (although there are near-shore oil-fields in production in the Pechora Sea). The greatest risks from future oil-production are associated with near-shore areas, especially in ecologically valuable areas like the Lofoten Islands, the polar front etc. In ice-free areas further off-shore the risk is greatly reduced. Therefore the current, overall risk of accident from an oil-installation in the Barents sea is much lower than for shipping. Even so, there is large concern about this risk as it comes from new human activities that can be totally avoided if off-shore oil is not developed.

In Table 8.1 the likelihood of an accident affecting the ecosystem at different stages in hydrocarbon extraction is estimated (Bienko and Berkovits, 2006). This analysis showed that the likelihood of effects from the gas pipeline was lower than from surface transport.

Table 8.1. Ecological risks associated with oil and gas mining and raw material transportation in the Barents Sea.

Object	Likelihood 1/year
Exploration drilling platform	1.9×10^{-3}
Production platform	5.6×10^{-3}
Floating oil storage	$10^{-2} – 10^{-3}$
Oil pipeline (platform-coast)	2.8×10^{-3}
Area of gulf/	2×10^{-4}
Sea	$2\times10^{-5} – 10^{4}$
Gas pipeline	$10^{-5} – 10^{-6}$

The experience from laying the deep-water pipeline “Goluboj potok” (“Blue flow”) (396 km along the bottom of the Black Sea), and from gas pipeline in the North Sea support the likelihood estimates from the Barents Sea (Table 1). The estimated probability of a large accidents during a single year for the pipelines with 1,000 km length is 10^{-4} , but experience from actual pipelines show an increases to 10^{-2} after long-term exploitation (Binenko, Berkovits, 2006).

8.2 Ship transport

Transport of oil and other petroleum products from ports and terminals in NW-Russia have been increasing steadily over the last decade (see Figure 8.1). In 2002, more than 4 million tons of Russian oil was exported along the Norwegian coast, in 2004, the volume reached almost 12 million and estimates show that in 2010, Russia may export of to 150 million of tons (Bambulyak, Frantsen, 2005). Every week in 2006 an average of 4 tankers (typically of ~ 50 000 tons tonnage) passed the Norwegian coast carrying crude oil to ports in Europe and USA. The shipping lanes are typically 12 – 30 nmi offshore, and in case accidents the vessels and cargo (oil) will be carried by the currents to the coast and along the coast into the Barents sea. Therefore, this risk of a major accident with such a tanker is one of the largest environmental risks posed to the Barents Sea ecosystem.

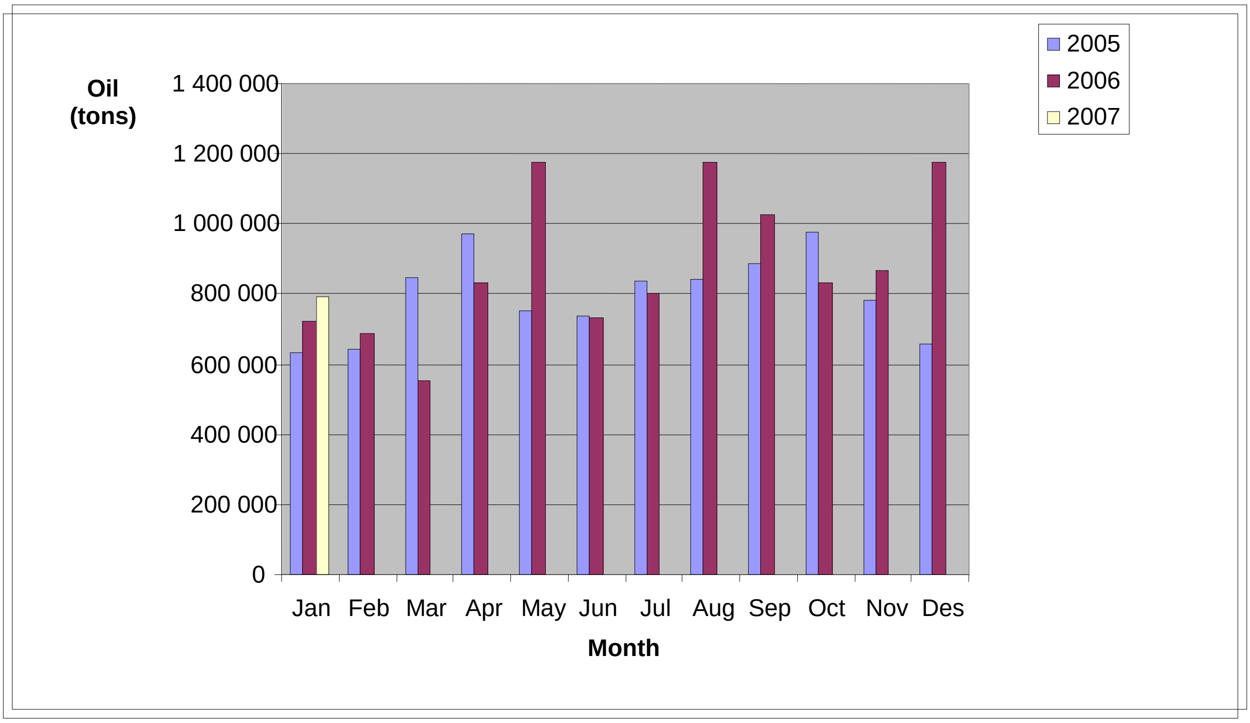

Figure 8.1. Amount of oil passing the Norwegian coast each month from oil-terminals in NW-Russia. Data from 2005 – 2007 is shown. (The figure is developed by the Norwegian Coastal Authorities).

Table 8.2. Estimates of frequency of oil discharge risk to the Barents Sea from shipping

Characteristics of discharges	**Frequency of event/year**	
1. Estimate by system of freight turnover		
Discharges with volume of 7 tons and higher	1.05×10^{-2}	3.12×10^{-2}
Discharges with volume of 700 tons and higher	2.21×10^{-3}	6.55×10^{-3}
2. Estimate of oil export allowing for handling		
Discharges in the sea with the volume of more than 153 m^3	5.87×10^{-2}	1.71×10^{-1}
Discharges at ports and in terminals with volume of over 153 m^3	3.87×10^{-2}	1.13×10^{-1}
3. Estimate by the number of shipments at ports and in terminals		
Discharges at ports and in terminals with volume of over 1 t	9.40×10^{-2}	$2..28\times10^{-1}$
Discharges at ports and in terminals with volume of over 10 t	1.88×10^{-2}	4.46×10^{-2}
Discharges at ports and in terminals with volume of over 100 t	3.58×10^{-3}	8.68×10^{-3}

Russian regulations use the volume of two tanks (over 12 000 tons for tankers larger than 70 000 tons) as a directive indicator for planning and sizing the facilities of the accident oil discharge liquidation system (LARN). Analyses of modeled spills have shown that an oil-spill from a supertanker (50 – 120 000 tons) may affect up to 14,000 km^2 of sea-surface and impact over 4,000 km of shoreline (Anon, 2001; Zhuravel, 2005). Accidents with tankers carryin gas condensate (5 – 15 000 tons) may affect 50 – 500 km^2. The economic result of the large oil spill for the fishing sector in the Barents sea is estimated to a loss in first-hand sales value of 0.3 – 1.2×10^9 US$ in the first year, not including the costs for cleaning up after the spill (Anon., 2001).

In table 2 we have shown the estimated frequency of discharges from ship transport in the Barents Sea based on the limited data available on sailing under arctic conditions (Zhuravel, 2005).

Constant leakages of hydrocarbons from the pipelines or from spills during loading tankers at terminals are very dangerous even if their immediate effects are minro. The economic damage from the gradual increase in the background hydrocarbon contamination cannot be estimated directly until this background level exceeds a threshold value, which is critical for the ecosystem (Anon., 2001).

Transport of oil and gas is therefore a real and present risk to the ecosystem as the transport of oil is ongoing, and will continue into the foreseeable future. Recent accidents with oil tankers in other parts of the world show the real and major dangers such accidents pose. The potential for a major accident, and its consequences has been the topic of several studies carried out in relation to the development of the Norwegian management plan for the Barents Sea. The management plan puts in place several tools to reduce this risk:

- Shipping lanes further offshore to increase reaction time in case a tanker gets into difficulties
- Sufficient tug-boat capacity along the Norwegian coast to be able to assist tankers in difficulties
- Development of oil-spill equipment and techniques suitable for the conditions in the Barents sea

These measures will decrease the likelihood and consequences of possible accidents, and thereby reduce the overall risk posed by shipping traffic.

8.3 Introduced species

Introduction of alien species can pose great risks to individual species, habitats or the state and function of the ecosystem as a whole. In general marine systems are more robust to introduced species there are fewer barriers that prevent the distribution of species. Even so, introduced marine species may supplant native species, deplete prey populations, affect habitat etc. We are unsure how the two introduced/alien crustacean species king crab (*Paralithodes camtschaticusi)* and snow crab (*Chionoecetes opilio)* may affect the ecosystem, but there is a risk that they may have negative impact. However, both species are monitored closely, and the consequences of these instructions are the topic of study.

Introduction of aliens with ballast water has been a global problem for a long time and is aptly referred to as “ecological roulette” because of its unpredictable character (Carton, Geller, 1993). Every introduction of an alien species does not necessarily result in appreciable ecologic, however with the increasing transport volumes the rate of introduction increases and the consequences grow. For instance, the introduction of the North American ctenophore *Mnemiopsis leidyi* to the Black Sea in the early 1980s caused a reduction in the anchovy stocks leading to an economic loss of 240 million US$ (Anon., 2001).

The main pathways for introduction to the Barents Sea area are by vessels carrying encrusting organisms and the non-controlled discharge of ballast waters to sea, in particular, to the Kola Bay. At present, there is no legislations (national or international) dealing with encrusting organisms The main reason is the difficulty for control. The situation for ballast waters is somewhat better. Estimation of risk of biological invasions with ballast waters is one of the main elements of “GloBallast” programme. The estimation of risk consists of calculating the probability of new species being introduced to an area when ballast water is changed/discharged. The estimation of biological invasions with encrusting organisms may be analogous (Zvyagintsev, Guk, 2006). It should be noted that the problem of risk of biological invasion to the Barents Sea is peculiar. Due to hydrology and water regime the Barents Sea is constantly subjected to the transport of organisms with waters of the North Atlantic Current (Gulf Stream). The Barents Sea ecosystem has been formed through thousands of years and it has been existing in such conditions. The temperature regime in the Sea is very unfavorable for organisms transported from temperate/boreal latitudes. Allowing for the main direction of hydrocarbon raw material transport – to the West Europe and back, through waters of the North Atlantic Current – the damage for the Barents Sea ecosystem as a result of undesirable species introduction may be considered *a priori* as potentially insignificant though the risks of the new species appearance may be quite high.

Alien species to the ecosystem may also pose the risk of being energetic “dead-ends”, eg. energy sinks that no other predator in the system can exploit. Invasions of alien species of jellyfish are examples of this kind of “dead-end” scenario, and a real and serious threat to the Barents Sea ecosystem. Although not an introduction, the recent expansion of the range of snake pipefish (*Entelurus aequoreus*) is an example of a potential “dead-end” species. Pipefish are long and have bony scales forming a stiff “exo-skeleton”. Their length and stiff outer body make them unsuitable as prey for typical predators of pelagic fish, eg. predatory fish, seabirds, whales and seals. Therefore the risk of introduction of species that may severly change the energy-pathways of the ecosystem is a real and serious threat to the ecosystem. This may even be increased in the coming decades as the effect of global warming leads many more southern species to the Barents Sea.

Again, these risks have been evaluated in the development of the Norwegian management plan for the Barents Sea, but only as worst-case scenarios. It is difficult, if not impossible to eliminate the risk of such introductions, although much can be done by regulations of treatment of ballast-water. However, an important tool to handle this risk is monitoring of the whole ecosystem to detect alien species when they arrive, and assess their potential risk before they achieve too large populations in the Barents Sea.

8.4 Conclusions

All human activities poses risks to the Barents Sea ecosystem, and this risk increases as a function of the probability, which itself is a function of the intensity of the human activity in question. The human activities with the highest activity therefore have an intrinsically higher risk than a low intensity activity. Ship transport is and has been a high intensity human activity in the Barents Sea, and at present the transport of oil from NW-Russia is the activity with the highest associated risk. However, this may change in the future as off-shore oil and gas exploration and production increases. Also, global warming will impact the Barents Sea severely, and it is very unsure how this will affect the distribution of southerly species into the Barents Sea and their impacts on the native flora and fauna.

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Benthic communities at the Barents Sea ice edge in a changing climate (BASICC)
A Norwegian - Russian co-operation project:
http://www.ecoserve.ie/projects/basicc/

Documentation on the EcoCod model: http://www.assessment.imr.no/request/index.html.

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Appendix 1. List of fish species recorded in the Barents Sea, according to literature, survey data and recent reviews of taxonomy. The list has been commented by Ingvar Byrkjedal, Bergen museum (see comments). Some species observation needs confirmation (NC) either by photo or sample.

Valid name	Zoogeogr. group	Ecological group	Comments
Myxini			
Myxiniformes			
Myxinidae			
Myxine glutinosa (Linnaeus, 1758)	BA	NB	
Cephalaspidomorphi			
Petromyzontiformes			
Petromyzontidae			
Petromyzon marinus (Linnaeus, 1758)	SBA	A	
Lampetra fluviatilis (Linnaeus, 1758)			
Lethenteron camtschaticum (Tilesius, 1811)	MB	A	
Elasmobranchii			
Hexanchiformes			
Chlamidoselachidae			
Lamniformes			
Lamnidae			
Lamna nasus (Bonnaterre, 1788)	SBA	EP	
Cetorhinidae			
Cetorhinus maximus (Gunnerus, 1765)	WD	EP	
Alopiidae			

Alopias vulpinus (Bonnaterre, 1788)			NC
Carcharhiniformes			
Scyliorhinidae			
Galeus melastomus (Rafinesque 1810)	SBA	EP	NC, known distribution N to about Tromsø
Scyliorhinus caniculus (Linnaeus, 1758)			NC, rare north of Helgeland
Triakidae			
Galeorhinus galeus (Linnaeus, 1758)	WD	EP	
Prionace glauca (Linnaeus, 1758)	WD	EP	NC
Squaliformes			
Squalidae			
Etmopterus spinax (Linnaeus, 1758)	WD	NBP	
Somniosus microcephalus (Bloch et Schneider 1801)	MB	NBP	
Squalus acanthias (Linnaeus, 1758)	WD	NBP	
Rajiformes			
Rajidae			
Bathyraja spinicauda (Jensen, 1914)	MB	B	
Dipturus batis (Linnaeus, 1758)	BA	B	
Raja clavata (Linnaeus, 1758)			NC, found north to Tromsø region
Leucoraja fullonica (Linnaeus, 1758)	BA	B	
Rajella fyllae (Lütken, 1888)	BA	B	
Amblyraja hyperborea (Collett, 1879)	A	B	
Dipturus linteus (Fries, 1838)	BA	B	
Dipturus oxyrinchus (Linnaeus, 1758)	BA	B	NC, found north to Tromsø region
Amblyraja radiata (Donovan, 1808)	MB	B	
Myliobatiformes			
Dasyatidae			

Holocephali			
Chimaeriformes			
Chimaeridae			
Chimaera monstrosa (Linnaeus, 1758)	BE	NB	
Teleostomi			
Notacanthiformes			
Notacanthidae			
Notacanthus chemnitzii (Bloch 1788)	WD	MB	NC, rare NE of Shetland-Iceland
Anguilliformes			
Anguillidae			
Anguilla anguilla (Linnaeus, 1758)	SB	C	
Congridae			
Conger conger (Linnaeus, 1758)			NC, rare north of Trøndelag
Synaphobranchidae			
Synaphobranchus kaupii (Johnson, 1862)			slope/deep-sea, unpubl. specimen in Bergen Museum
Clupeiformes			
Clupeidae			
Alosa alosa (Linnaeus, 1758)			NC
Clupea harengus (Linnaeus, 1758)	MB	NP	
Clupea pallasi marisalbi (Berg, 1923)		NP	Depending on limits of Barents Sea, White Sea eastward to Ob
Clupea pallasii suworowi (Rabinerson 1927)		NP	Depending on limits of Barents Sea, near Kanin Nos
Sprattus sprattus (Linnaeus, 1758)			NC, rare as far north as Troms
Salmoniformes			
Argentinidae			
Argentina silus (Ascanius, 1775)	BA	BP	
Argentina sphyraena (Linnaeus, 1758)			NC, to be expected as vagrant

Microstomatidae			
Nansenia groenlandic (Reinhardt, 1840)		BP	
Osmeridae			
Osmerus eperlanus (Linnaeus, 1758)	BE	A	
Mallotus villosus (Müller, 1776)	MB	NP	
Salmonidae			
Salmo salar (Linnaeus, 1758)	MB	A	
Salmo trutta (Linnaeus, 1758)	BE	A	
Oncorhynchus mykiss (Walbaum, 1792)			Depending on limits of Barents Sea,
Salvelinus alpinus (Linnaeus, 1758)	A	A	
Oncorhynchus gorbusha (Walbaum, 1792)	MB	A	
Oncorhynchus keta (Walbaum, 1792)	MB	A	
Stomiiformes			
Stomidae			
Chauliodus sloani (Bloch and Schneider, 1801)			slope
Sternoptychidae			
Argyropelecus hemigymnus (Cocco, 1829)	WD	BP	NC, slope, to be expected as vagrant
Argyropelecus olfersi (Cuvier, 1829)	WD	BP	
Maurolicus muelleri (Gmelin, 1789)	BA	BP	
Aulopiformes			
Paralepididae			
Arctozenus risso (Bonaparte, 1840)	WD	BP	
Myctophiformes			
Myctophidae			
Benthosema glaciale (Reinhardt, 1838)	MBA	BP	
Notoscopelus kroyeri (Malmgren, 1861)	MBA	BP	NC, distribution north to Shetland-Iceland

Gadiformes			
Macrouridae			
Macrourus berglax (Lacepede, 1810)	BA	NB	
Gadidae			
Arctogadus glacialis (Peters, 1874)	A	Cr	
Boreogadus saida (Lepechin, 1774)	A	Cr	
Eleginus navaga (Pallas, 1811)	A	NBP	
Gadiculus argenteus thori (Schmidt, 1914)	SBE	BP	
Gadus morhua (Linnaeus, 1758)	MBA	NBP	
Melanogrammus aeglefinus (Linnaeus, 1758)	MBA	NBP	
Merlangius merlangus (Linnaeus, 1758)	SBE	NBP	Depending on limits of Barents Sea, very rare along coast of N Norway
Micromesistius poutassou (Risso, 1826)	MBA	NP	
Pollachius pollachius (Linnaeus, 1758)	BE	NP	
Pollachius virens (Linnaeus, 1758)	MBA	NP	
Theragra finnmarchica (Koefoed, 1956)	BA	NBP	
Trisopterus esmarkii (Nilsson, 1855)	BE	NP	
Lotidae			
Brosme brosme (Ascanius, 1772)	MB	NB	
Ciliata mustela (Linnaeus, 1758)	BE	NB	
Ciliata septentrionalis (Collett, 1875)	BE	NB	NC, coast, recorded north to Troms; probably very rare anywhere
Enchelyopus cimbrius (Linnaeus, 1766)	BA	NB	coast & slope,
Gaidropsarus argentatus (Reinhardt, 1838)	A	NB	
Molva dypterygia (Pennant, 1784)	BA	NB	
Molva molva (Linnaeus, 1758)	BA	NB	
Raniceps raninus (Linnaeus, 1758)		NB	NC, coast, northwards to Lofoten
Phycidae			

Phycis blennoides (Bruennich, 1768)	SBE	NBP	NC, slope, recorded north to Troms
Merluccidae			
Merluccius merluccius (Linnaeus, 1758)	BE	NBP	NC, rare north of Helgeland
Lophiiformes			
Lophiidae			
Lophius piscatorius (Linnaeus, 1758)	SBA	B	
Antennariidae			
Histrio histrio (Linnaeus, 1758)	WD		
Beloniformes			
Scomberesocidae			
Scomberesox saurus (Walbaum, 1792)	WD	EP	
Belonidae			
Belone belone (Linnaeus, 1761)	BE	NP	
Lampriformes			
Lampridae			
Lampris guttatus (Brünnich, 1771)	WD	EP	
Trachipteridae			
Trachipterus arcticus (Brünnich, 1771)	WD	BP	
Regalecidae			
Regalecus glesne (Ascanius, 1772)	WD	BP	
Beryciformes			
Berycidae			
Beryx decadactylus (Cuvier, 1829)	WD	NB	
Gasterosteiformes			
Gasterosteidae			
Gasterosteus aculeatus (Linnaeus, 1758)	MB	NP	

Pungitius pungitius (Linnaeus, 1758)			
Spinachia spinachia (Linnaeus, 1758)	BE	NP	NC, coast, rare N of Troms
Syngnathiformes			
Syngnathidae			
Entelurus aequoreus (Linnaeus, 1758)	BE	NP	
Nerophis lumbriciformis (Jenyns, 1835)			NC, coast, rare N of Trøndelag
Syngnathus typhle (Linnaeus, 1758)			
Scorpaeniformes			
Sebastidae			
Helicolenus dactylopterus (Delaroche, 1809)	SBA	NB	
Sebastes marinus (Linnaeus, 1758)	MB	NB	
Sebastes mentella (Travin 1951)	MB	NB	
Sebastes viviparus (Kröyer, 1844)	BA	NB	
Triglidae			
Eutrigla gurnardus (Linnaeus, 1758)	SBE	B	
Chelidonichthys lucerna (Linnaeus, 1758)			NC, coast, known north to Tromsø, might be expected in Barents Sea
Cottidae			
Artediellus atlanticus (Jordan et Evermann, 1898)	MB	B	
Artediellus scaber (Knipowitsch, 1907)	A	B	
Gymnocanthus tricuspis (Reinhardt, 1830)	MA	B	
Icelus bicornis (Reinhardt, 1840)	MA	B	
Icelus spatula (Gilbert et Burke, 1912)	AB	B	
Myoxocephalus scorpius (Linnaeus, 1758)	MBE	B	
Taurulus bubalis (Euphrasen, 1786)	BE	B	
Triglopsis quadricornis (Linnaeus, 1758)	A	B	
Triglops murrayi (Günther, 1888)	BA	B	

Triglops nybelini (Jensen, 1944)	A	B	
Triglops pingeli (Reinhardt, 1937)	AB	B	
Psychrolutidae			
Cottunculus microps (Collett, 1875)	MA	B	
Cottunculus sadko (Essipov, 1937)	A	B	
Agonidae			
Agonus cataphractus (Linnaeus, 1758)	BE	B	
Leptagonus decagonus (Bloch et Schneider, 1801)	AB	B	
Ulcina olrikii (Lütken, 1876)	A	B	
Cyclopteridae			
Cyclopteropsis macalpini (Fowler, 1914)	A	B	
Cyclopterus lumpus (Linnaeus, 1758)	MBA	NBP	
Eumicrotremus derjugini (Popov, 1926)	A	B	
Eumicrotremus spinosus (Müller, 1777)	A	B	
Liparididae			
Liparis fabricii (Kröyer, 1847)	A	NB	
Liparis gibbus (Bean, 1881)	MA	B	
Liparis liparis (Linnaeus, 1766)	BE	B	coast, Depending on limits of Barents Sea, probably along coast of Finnmark
Liparis montagui (Donovan, 1805)	BE	B	coast, Depending on limits of Barents Sea, probably along coast of Finnmark
Liparis tunicatus (Reinhardt, 1837)	A	B	
Paraliparis bathybii (Collett, 1879)	A	NB	
Rodichthys regina (Collett, 1879)	A	NB	slope, Depending on limits of Barents Sea
Careproctus knipowitschi (following recent revision (Chernova 2005)			
Careproctus derjugini (following recent revision (Chernova 2005)			
Careproctus dubius (following recent revision (Chernova 2005)			

Careproctus macrophthalmus (following recent revision (Chernova 2005)			
Careproctus tapirus (following recent revision (Chernova 2005)			
Careproctus telescopus (following recent revision (Chernova 2005)			
Perciformes			
Bramidae			
Brama brama (Bonnaterre, 1788)	WD	BP	
Pterycombus brama (Fries, 1837)	SBA	BP	
Taractes asper (Lowe 1983)	WD	BP	NC, very rare NE of Faroes-Iceland
Callionymidae			
Callionymus lyra (Linnaeus, 1758)			
Carangidae			
Trachurus trachurus (Linnaeus, 1758)			NC, recorded N to Troms, but can be expected
Gempylidae			
Nesiarchus nasutus (Johnson, 1862)			
Zoarcidae			
Gymnelus andersoni (Chernova 1998)	A	B	
Gymnelus esipovi (Chernova 1999)	A	B	NC, known from the Arctic Ocean (Chernova 1999)
Gymnelus retrodorsalis (Le Danois 1913)	A	B	
Gymnelus taeniatus (Chernova 1999)	A	B	Depending on limits of Barents Sea, known from near Franz Josef Land
Lycenchelys kolthoffi (Jensen 1903)	A	B	
Lycenchelys muraena (Collett, 1878)	A	B	
Lycenchelys platyrhina (Jensen, 1901)	A	B	NC, slope,
Lycenchelys sarsii (Collett, 1871)	BE	B	
Lycodes esmarkii (Collett, 1875)	MBA	B	
Lycodes eudipleurostictus (Jensen, 1901)	A	B	

Lycodes frigidus (Collett, 1878)	A	B	
Lycodes jugoricus (Knipowitch, 1906)	A	B	
Lycodes luetkeni (Collett 1880)	A	B	NC, slope,
Lycodes pallidus (Collett, 1878)	A	B	
Lycodes polaris (Sabine, 1824)	A	B	
Lycodes reticulatus (Reinhardt, 1935)	A	B	
Lycodes rossi (Malmgren, 1864)	A	B	
Lycodes seminudus (Reinhardst, 1837)	A	B	
Lycodes squamiventer (Jensen, 1904)	A	B	
Lycodes gracilis (Sars, 1867)	MBE	B	
Lycodonus flagellicauda (Jensen, 1901)	A	B	
Zoarces viviparus (Linnaeus, 1758)	MBE	B	
<u>Stichaeidae</u>			
Chirolophis ascanii (Walbaum, 1792)	BA	B	
Anisarchus medius (Reinhardt, 1837)	BA	B	
Lumpenus fabricii (Valenciennes, 1836)	MA	B	
Lumpenus lampretaeformis (Walbaum, 1792)	MBE	B	
Leptoclinus maculatus (Fries, 1837)	MBA	B	
<u>Pholidae</u>			
Pholis gunnellus (Linnaeus, 1758)	MBA	B	
<u>Anarhichadidae</u>			
Anarhichas denticulatus (Kröyer, 1845)	MBA	NB	
Anarhichas lupus (Linnaeus, 1758)	MBA	B	
Anarhichas minor (Olafsen, 1772)	MBA	B	
<u>Ammodytidae</u>			
Ammodytes marinus (Raitt, 1934)	MBE	B	

Hyperoplus lanceolatus (Sauvage, 1824)	BE	B	
Trichiuridae			
Aphanopus carbo (Lowe 1983)	BA	BP	NC, slope, might be expected as vagrant
Bentodesmus elongatus (Clarke, 1879)			slope, rarely found NE of Shetland-Iceland
Xiphiidae			
Xiphias gladius (Linnaeus, 1758)	WD	EP	
Scombridae			
Scomber scombrus (Linnaeus, 1758)	SBA	NP	
Thunnus thynnus (Linnaeus, 1758)	WD	EP	
Sparidae			
Pagellus bogaraveo (Brünnich, 1768)			NC, recorded northward to Tromsø; expected vagrant in BS
Spondyliosoma cantharus (Linnaeus, 1758)			NC, very rare N of Trondheimsfjorden
Centrolophidae			
Centrolophus niger (Gmelin, 1788)	WD	NBP	
Schedophilus medusophagus (Cocco, 1839)			
Gobiidae			
Crystallogobius linearis (Dueben, 1845)			NC, rare north of Trondheimsfjorden
Gobiosculus flavescens (Fabricius, 1779)			NC, coast, recorded N to about Andøya
Pomatoschistus minutus (Pallas, 1770)			NC, coast, recorded north to Troms
Pomatoschistus norvegicus (Collett, 1902)			NC, coast, recorded north to Vestfjorden
Labridae			
Moronidae			
Dicentrarchus labrax (Linnaeus, 1758)	SBE	NBP	
Polyprion americanus (Bloch et Schneider, 1801)			
Mugilidae			
Chelon labrosus (Risso, 1826)			

<u>Pleuronectiformes</u>			
<u>Scophthalmidae</u>			
Lepidorhombus whiffiagonis (Walbaum, 1792)		B	NC, known distribution north to Vestfjorden
Phrynorhombus norvegicus (Günther, 1862)	BE	B	
Psetta maxima (Linnaeus, 1758)	BE	B	
Scophthahnus rhombus (Linnaeus, 1758)		B	NC, rare north of Trøndelag
<u>Pleuronectidae</u>			
Glyptocephalus cynoglossus (Linnaeus, 1758)	MBA	B	
Hippoglossoides platessoides (Fabricius, 1780)	MBE	B	
Hippoglossus hippoglossus (Linnaeus, 1758)	MBA	B	
Limanda limanda (Linnaeus, 1758)	MBE	B	
Liopsetta glacialis (Pallas, 1776)	MA	B	
Microstomus kitt (Walbaum, 1792)	BE	B	
Platichthys flesus (Linnaeus, 1758)	MBE	B	
Pleuronectes platessa (Linnaeus, 1758)	MBE	B	
Reinhardtius hippoglossoides (Walbaum, 1792)	MBA	B	
<u>Tetraodontiformes</u>			
<u>Molidae</u>			
Mola mola (Linnaeus, 1758)	WD	EP	

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