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JOINT PINRO/IMR REPORT ON THE STATE OF THE BARENTS SEA ECOSYSTEM 2005/2006

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Joint PINRO/IMR report on the state of the Barents Sea ecosystem 2005/2006

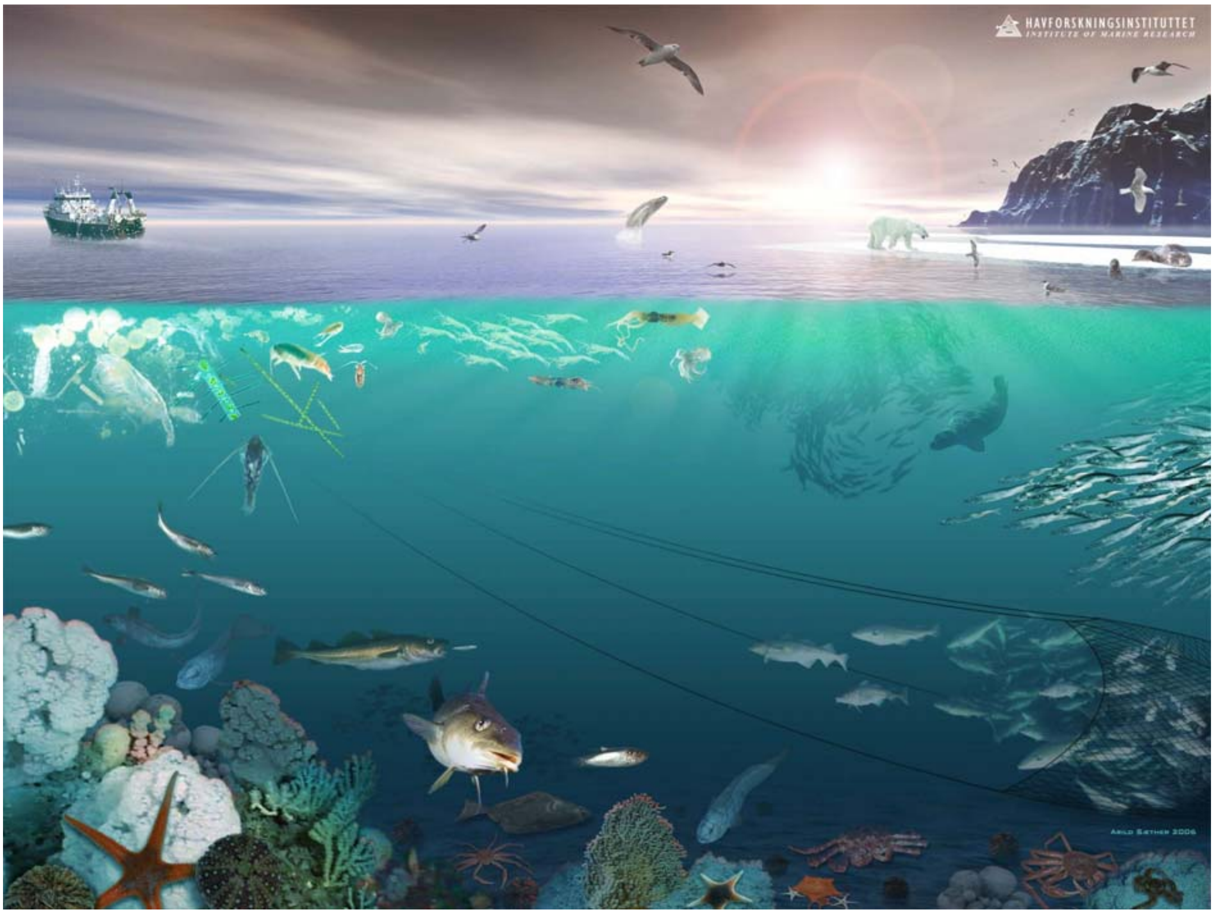

Figure 1.1. Illustration of the rich marine life and interactions in the Barents Sea.

by

J.E. Stiansen[1], A. Aglen[1], B. Bogstad[1], P. Budgell[1], P. Dalpadado[1], A.V. Dolgov[2], A. Dommasnes[1], A.A. Filin[2], H.Gjøsæter[1], K.H. Hauge[1], Å. Høines[1], R. Ingvaldsen[1], E. Johannesen[1], L.L. Jørgensen[1], A.L. Karsakov[2], J. Klungsøyr[1], T. Knutsen[1], V. Lien[1], H. Loeng[1], S. Mehl[1], P. B. Mortensen[1], N.V. Muchina[2], V.N. Nesterova[2], E. Olsen[1], E.L. Orlova[2], V.K. Ozhigin[2], A.P. Pedchenko[2], E.K. Stenevik[1], M. Skogen[1], O.V. Titov[2], S. Tjelmeland[1], V.B. Zabavnikov[2], S.V. Ziryanov[2], N.G. Zhukova[2], N. Øien[1], S. Aanes[1]

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Contents

1 Introduction

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.

For this reasons it was agreed on the annual March meeting in 2006 between scientists of IMR and PINRO 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. This report has developed from a working document to earlier AFWG meetings.

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.

The report has been divided into 6 main chapters. In chapter 2 the typical situation is given, and also the most important links in the ecosystem are identified. Chapter 3 gives an overview of the large effort that is put into surveillance. Chapter 4 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 next year, when possible. Chapter 5 is dedicated to the impact from the fisheries on the ecosystem, and chapter 6 gives an overview of the pollution. Models and ongoing work, which may be useful for management in the future, is presented in chapter 7.

In addition overview of the general and current situation is given in a summary sub-chapter in the beginning of chapter 2 and 4, respectively.

The main target group of this report is the scientific community. However, 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.

2 General description of the ecosystem

2.1 Overview of the ecosystem

The Barents Sea 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, 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 west, the top of the continental slope against the Arctic Ocean in north, Novaya Zemlya in east and the coasts of Norway and Russia in the south (Figure 2.1). 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. Warm Atlantic waters from the Norwegian Atlantic Current with a salinity of approx. 35‰ flows in through the western entrance. 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 relative strength of the two branches depends on the local wind conditions. South of the Norwegian Atlantic Current and along the coastline flows the Norwegian Coastal Current. 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. In the western Barents Sea the position of the front is well defined and relatively stable, but in the eastern part the position of this front has large seasonal, as well as year- to-year, variations. In general, the Barents Sea is characterised by large year-to-year variations in both heat content and ice conditions. The most important cause of this is variation in amount and temperature of the Atlantic water that enters the Barents Sea.

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. 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. 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 the Barents Sea ecosystem. *Calanus finmarchicus*, which is most abundant in the Atlantic waters, is the main contributor to the zooplankton biomass. *C. glacialis* is the dominant contributor to zooplankton biomass of the Arctic waters of the

Barents Sea. The *Calanus* species are predominantly herbivorous, feeding especially on diatoms (Mauchline, 1998). Krill (euphausiids) is another group of crustaceans playing 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 *Th. inermis* and neritic coastal arcto-boreal *Th. 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 *Th. raschii* increases and the abundance of *Th. inermis* – decreases, while after a number of warm years the abundance of *Th. 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).

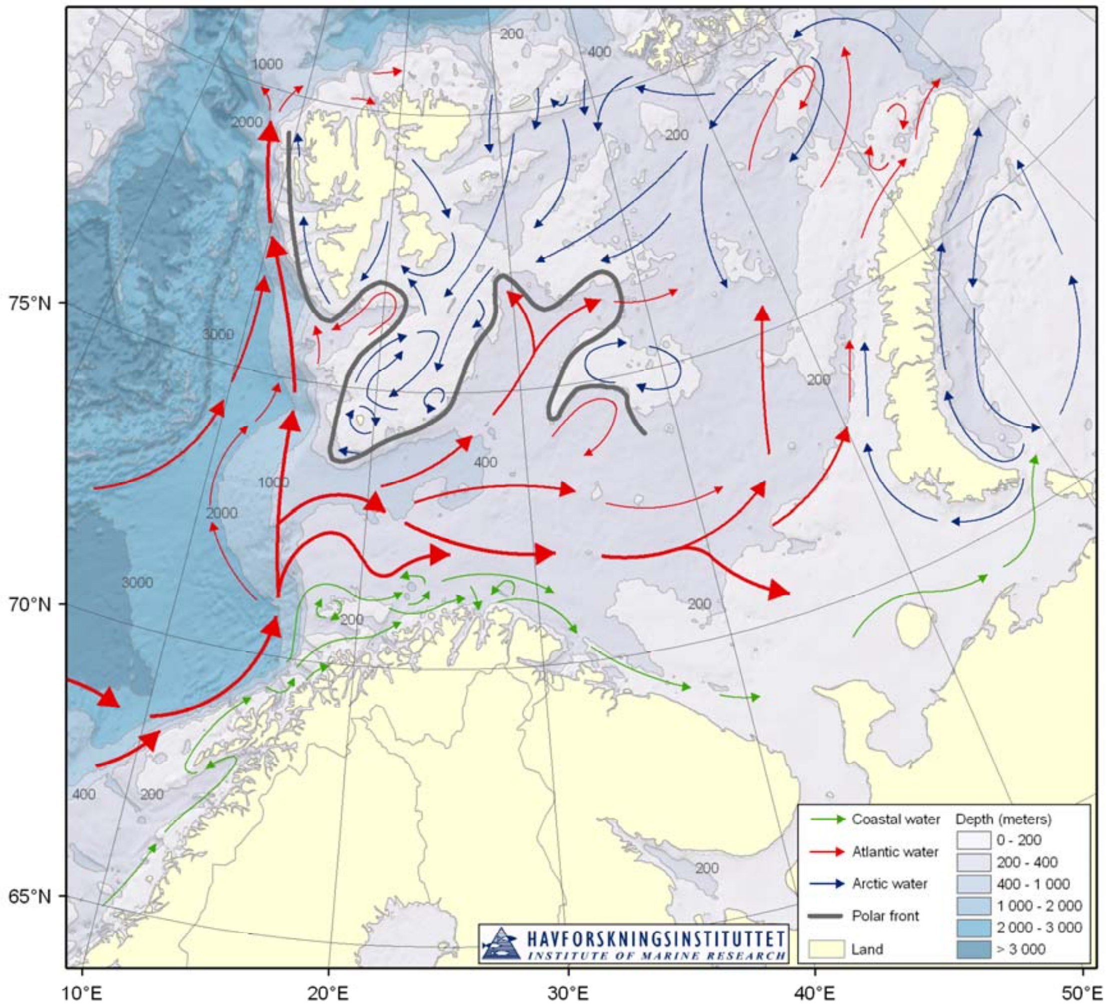


Figure 2.1. The main features of the circulation and bathymetry of the Barents Sea.

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 of the Barents Sea. *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 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. 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.

The Barents Sea is a relatively simple ecosystem with few fish species of potentially high abundance. These 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 composition and 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*). The currently available abundance estimates of the most abundant larger cetaceans in the north-east Atlantic (i.e. comprising the North, Norwegian, Greenland and Barents Seas) are: minke whales 107,205; fin whales *B. physalus* 5,400; humpback whales *Megaptera novaeangliae* 1,200; sperm whales *Physeter catodon* 4,300 (Skaug *et al*., 2002; Øien, 2003; Skaug *et al*., 2004). *Lagenorhyncus* dolphins are the most numerous smaller cetaceans, with an abundance of 130,000 individuals (Øien, 1996), while harp seals are the most numerous seal in the Barents Sea with approximately 2.2 million individuls. 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).

2.2 Geographical description

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.

2.3 Climate

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).

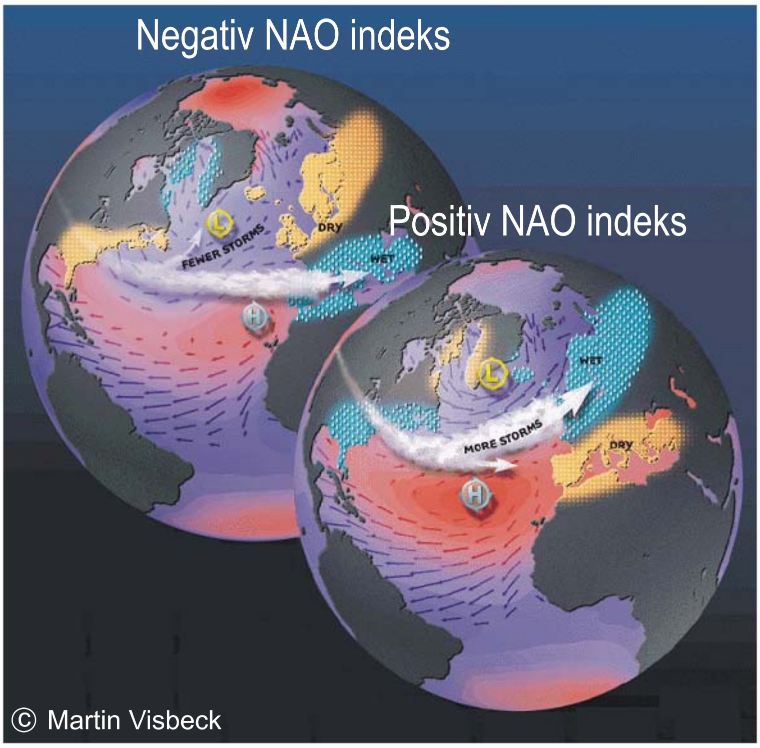
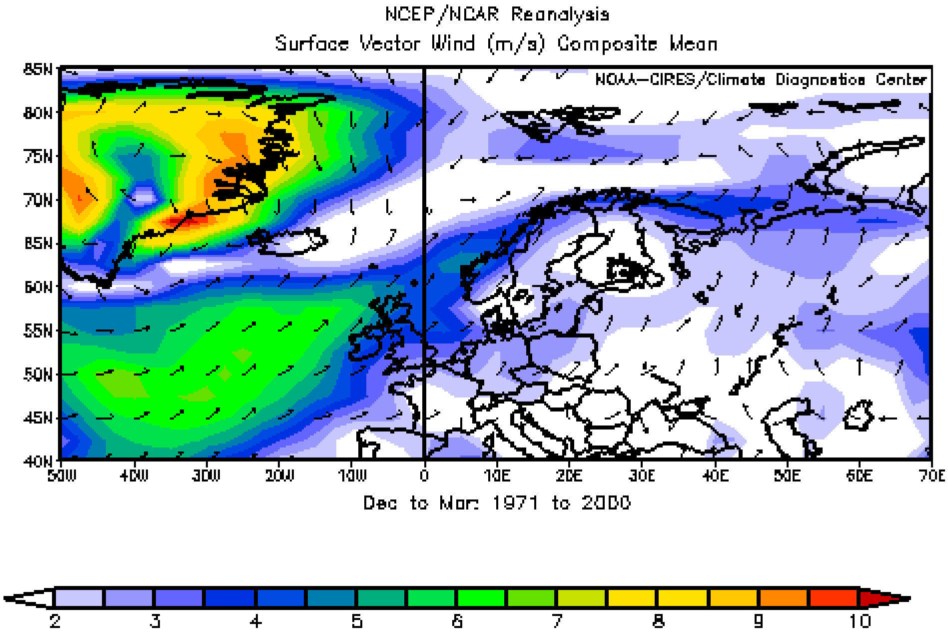


Figure 2.2. A positive NAO phase (bottom right globe) is characterized by a marked difference in air pressure between the low-pressure centre near Island and the high-pressure centre further south in the North Atlantic. In a positive NAO phase the dominating winds will be stronger than average and have 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. 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 (Figure 2.4). 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.



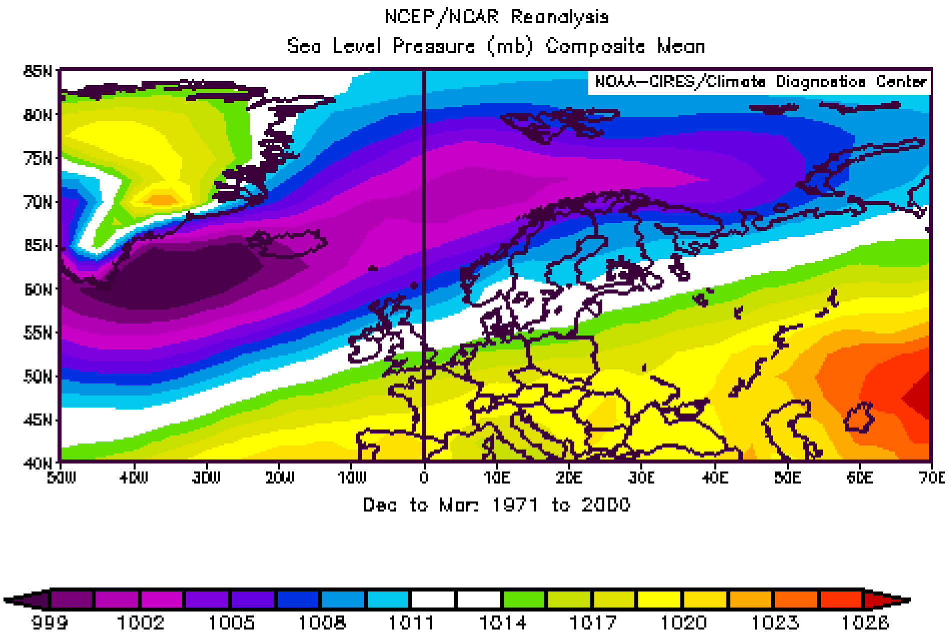
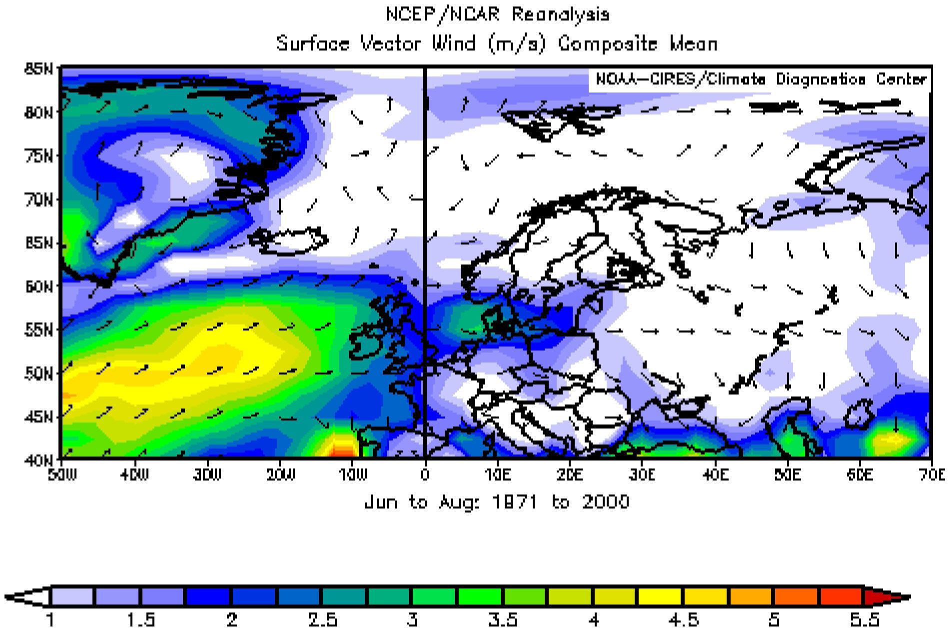


Figure 2.3. The long-term mean (1971-2000) sea level pressure (above) and wind vectors (below) in December-March.



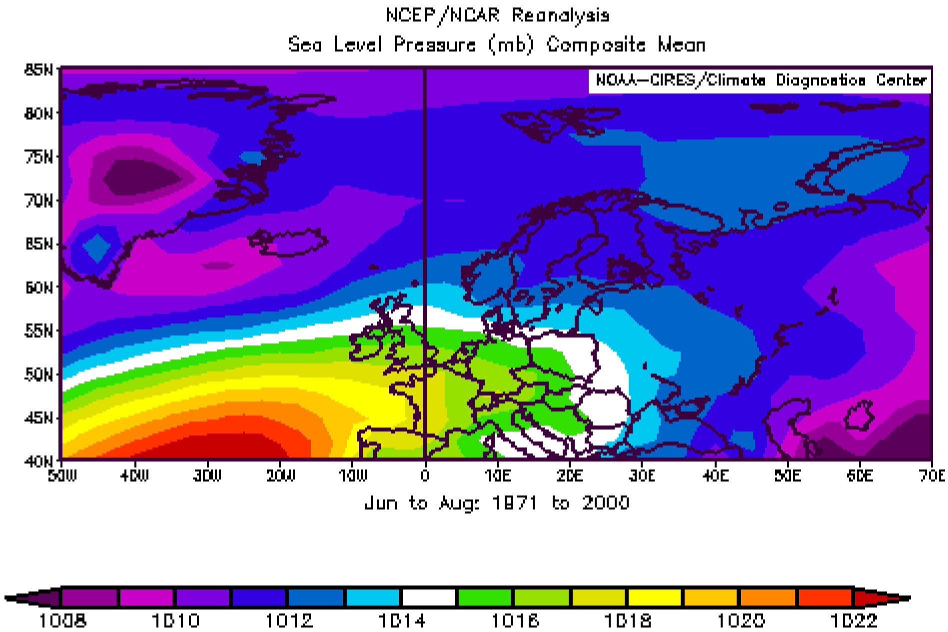


Figure 2.4. The long-term mean (1971-2000) sea level pressure (above) and wind vectors (below) in June-August.

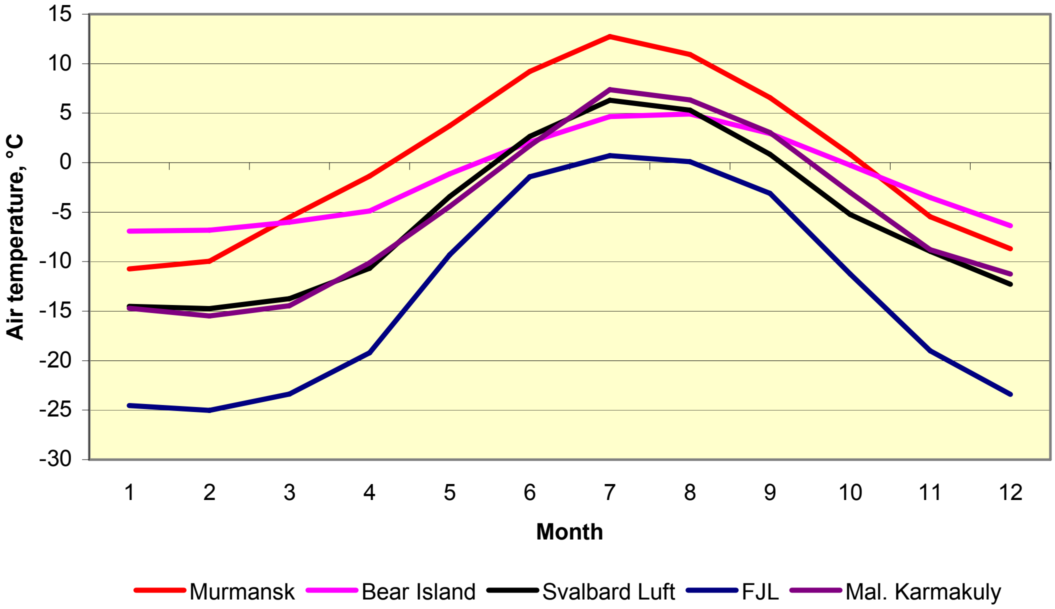


Figure 2.5. Climatic seasonal cycle of air temperature at stations Spitsbergen airport, Bear Island, Murmansk, Malye Karmakuly (southern Novaya Zemlya) and Franz Josef Land (GMO Im. E.T.).

2.3.2 General circulation, water masses and 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. For this reason, water with salinity down to 34.95 is commonly classified as water of Atlantic origin. In the southwest 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, build-up and erosion of stratification are mainly determined by wind and air temperature. 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 warming 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, 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 the maximum (summer) values are reached in August-September and the minimum (winter) values in February-March. Seasonal development in the southern areas is shown in Figure 4.10.

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.

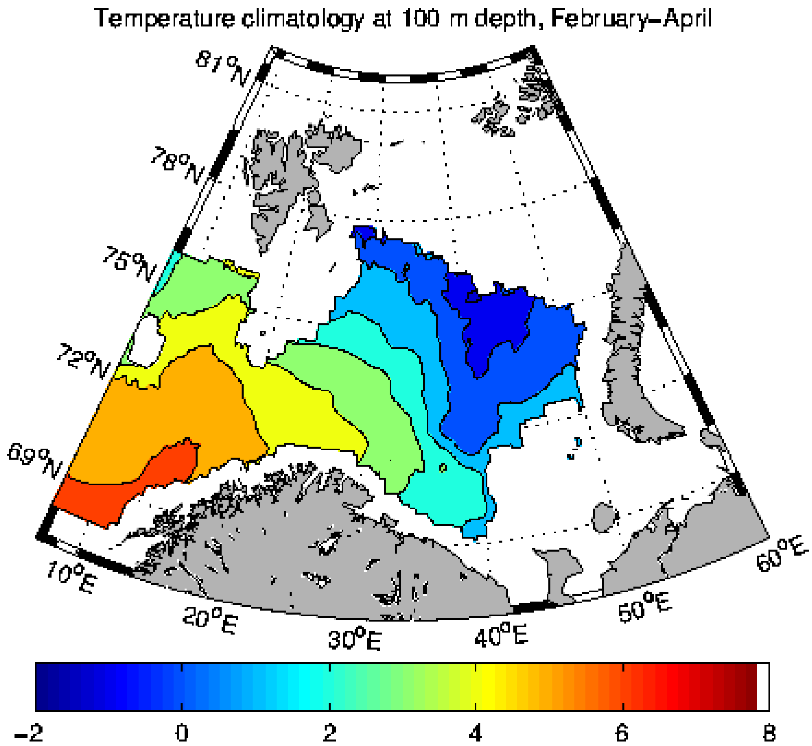


Figure 2.6. Average winter temperatures in the Barents Sea at 100 m. Based on observations in February-April for the periode 1977-1996. Please note that in any specific year the Polar front is quite sharp. This is not evident in the figure due to winter ice cover (and therebye few data in the northern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

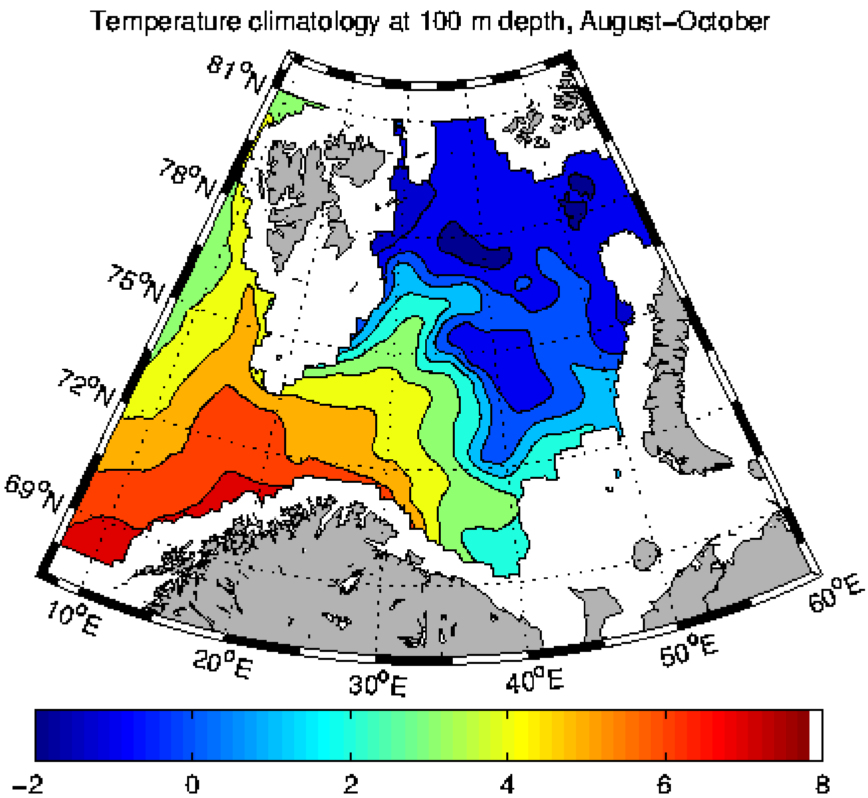


Figure 2.7. Average summer temperatures in the Barents Sea at 100 m. Based on observations in August-October for the periode 1977-1996.

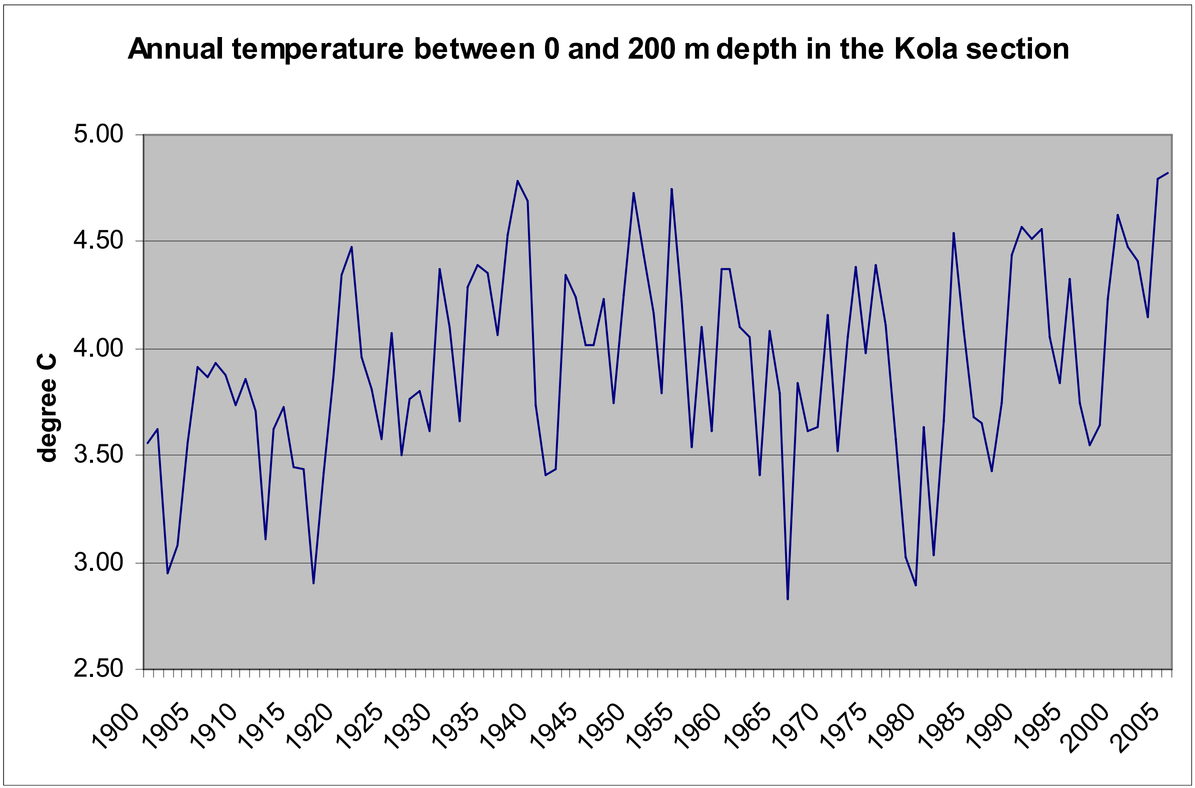


Figure 2.8. Average annual temperature between 0 and 200 m depth in the Kola section, stations 3-7 (Bochkov, 1982, 2005).

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 main 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^{o}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 is 1.7 Sv during winter and 1.3 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.

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. The ice has a relatively short response time on temperature change (about one year), but usually the sea ice distribution in the eastern Barents Sea responds a bit later than in the western part.

2.4 Species communities

2.4.1 Phytoplankton

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* 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*.

2.4.2 Zooplankton

Zooplankton acts as a link between phytoplankton (primary producers) and fish, mammals and other organisms at higher trophic levels. The most abundant zooplankton, copepods, krill and hyperiid amphipods in the Barents Sea 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 reproduction of both *C. finmarchicus* on the Atlantic side and *C. glacialis* on the Arctic side of the front is connected to the phytoplankton ice-edge bloom and the favorable production conditions at the ice edge support large concentrations of crustaceans and other species of zooplankton. 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.

2.4.3 Fish

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 2.9Figure 2.10). 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.

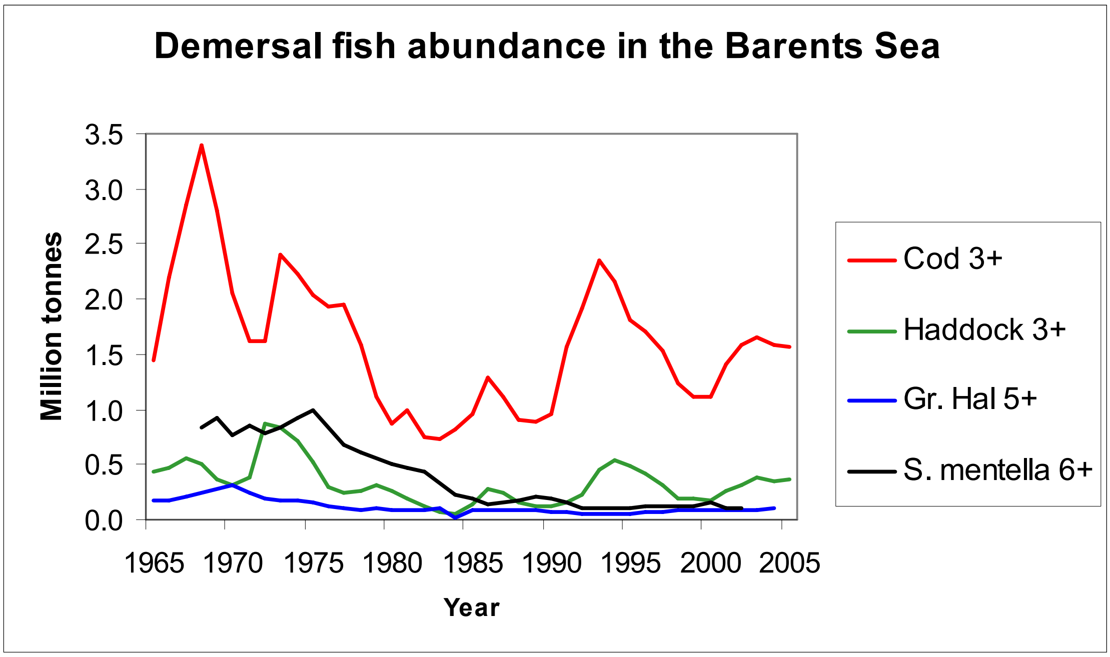


Figure 2.9. Abundance of demersal fish species in the Barents Sea. The data are taken from; cod: VPA estimates, age 3+ (ICES, 2005); haddock: VPA estimates, age 3+ (ICES, 2005); Greenland halibut: VPA estimates, age 5+ (ICES, 2005); Sebastes mentella: VPA estimates, age 6+ (ICES, 1995 for the years 1968-1990; ICES, 2003 for the years 1991-2002).

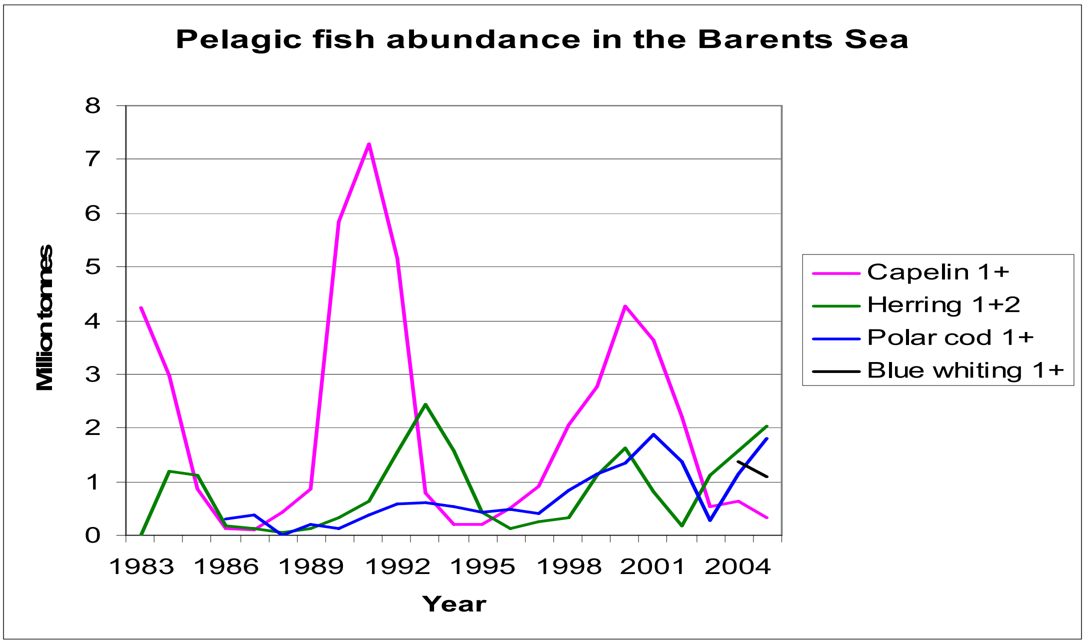


Figure 2.10. Abundance of pelagic fish species in the Barents Sea. The data are taken from; capelin: Acoustic estimates in September-October, age 1+ (ICES, 2005; Anon., 2005;, herring: VPA estimates of age 1 and 2 herring (ICES/ACFM:05, 2006) using standard weights at age (9 g for age 1 and 20g for age 2); polar cod: Acoustic estimates in September-October, age 1+ (Anon., 2005); blue whiting: Acoustic estimates in September-October, age 1+ (Anon., 2004; Anon., 2005).

Cod

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.

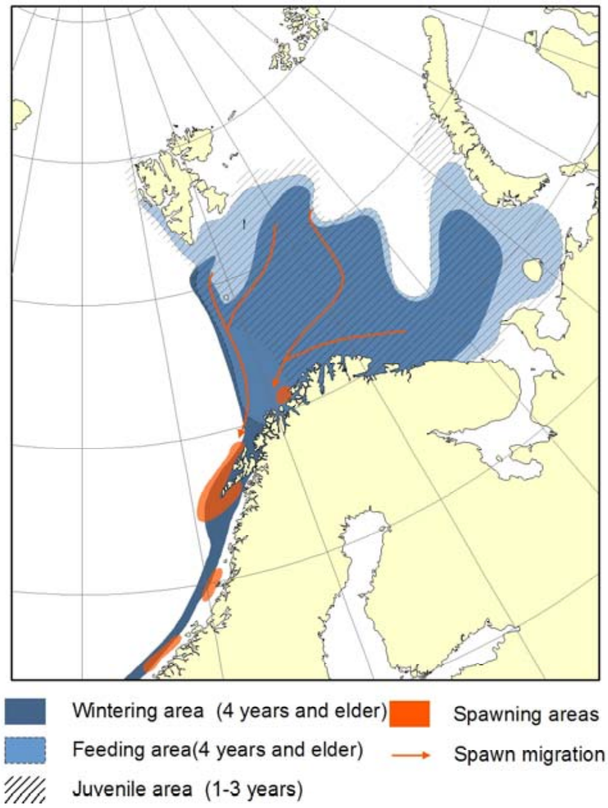


Figure 2.11. Distribution area for Northeast Arctic Cod.

Haddock

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.

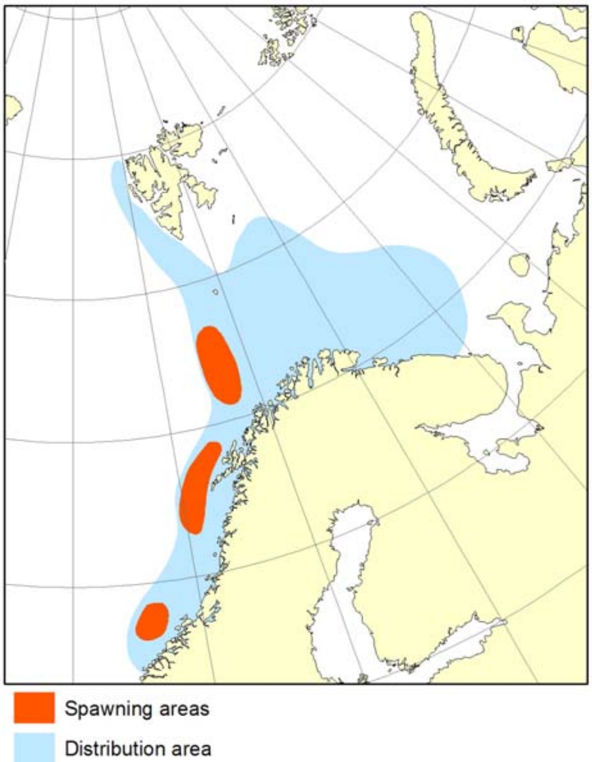


Figure 2.12. Distribution area for Northeast Arctic Haddock.

Redfish

Deep-sea redfish and golden redfish 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 planktoneaters 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 2.13. Distribution area for Deep Sea redfish (lower) and golden redfish (upper) in the Barents Sea region.

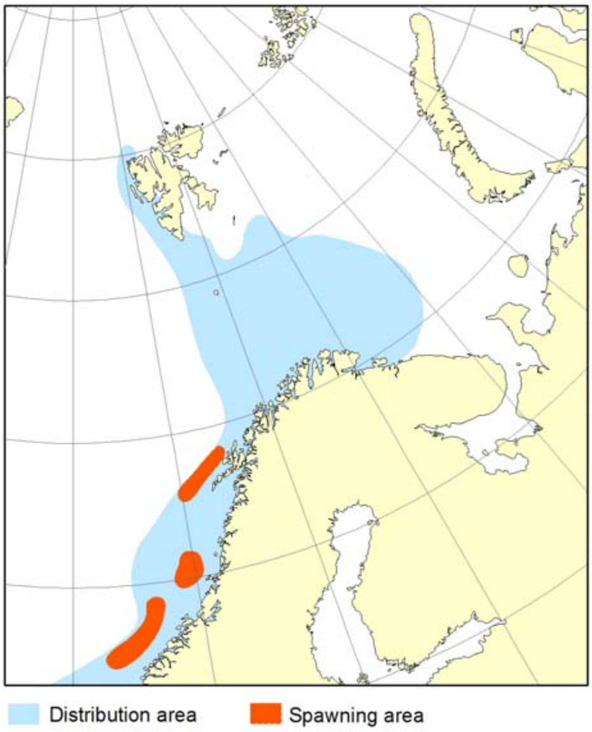


Figure 2.13. Distribution area for Deep Sea redfish (lower) and golden redfish (upper) in the Barents Sea region.

Greenland halibut

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.

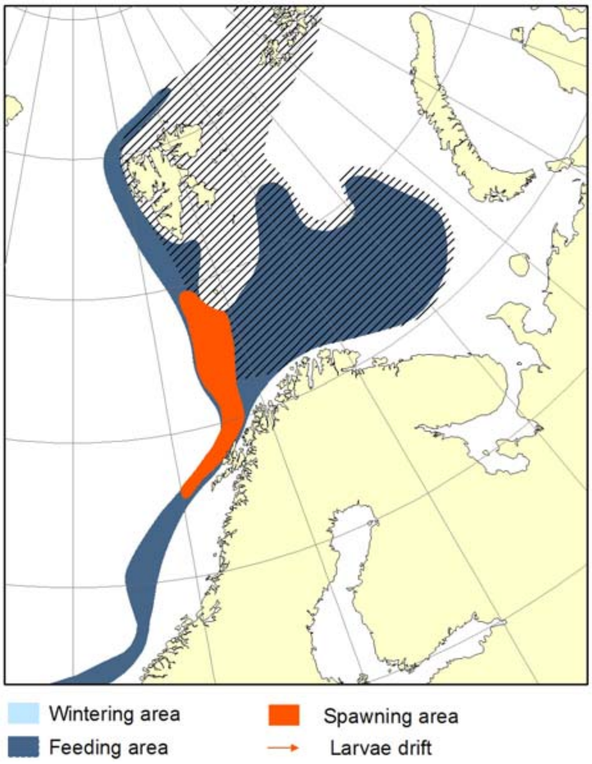


Figure 2.14. Distribution area for Northeast Arctic Greenland halibut.

Capelin

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).

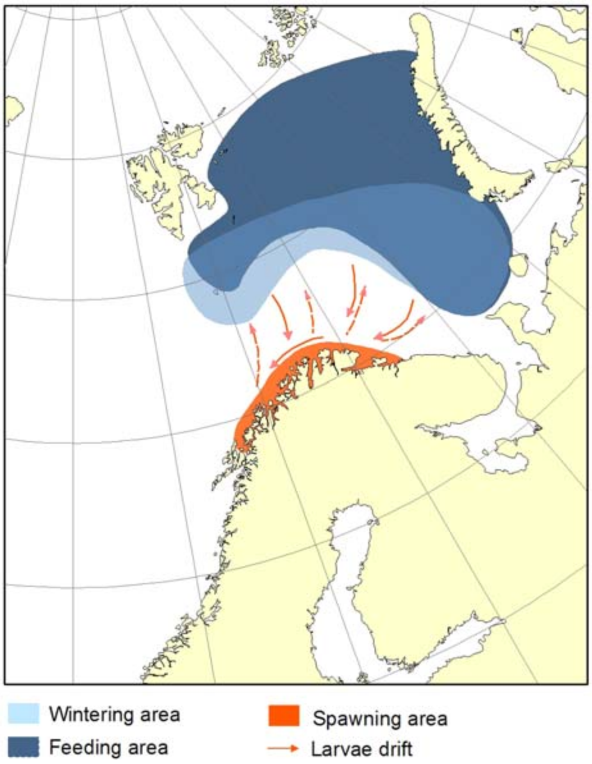


Figure 2.15. Distribution area for Barents Sea capelin.

Herring

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 stoc. In this way, the herring stock has impact both on the capelin stock (directly) and the cod stock (indirectly).

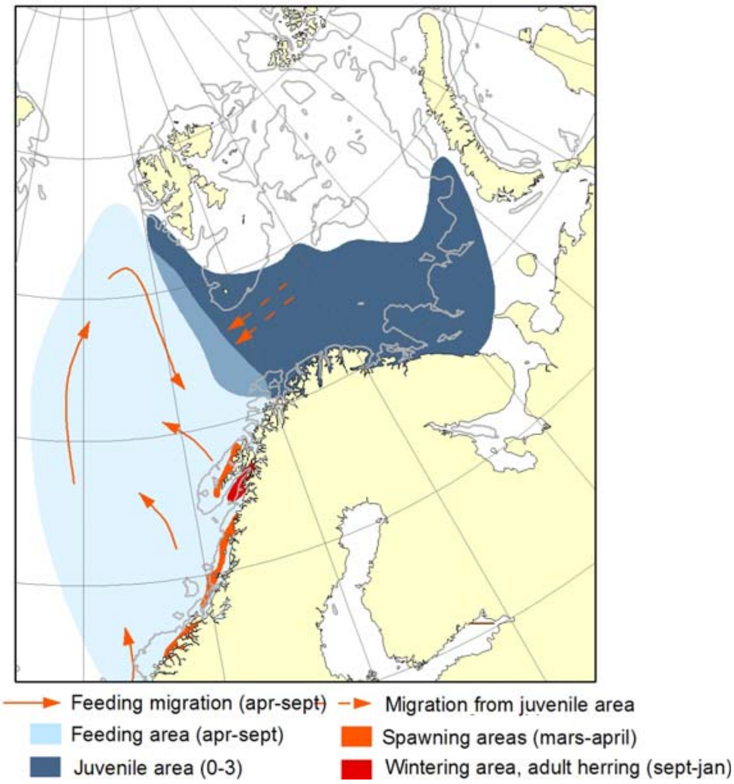


Figure 2.16. Distribution area for Norwegian spring spawning herring.

Polar cod

Polar cod is a cold-water species found particularly in the eastern Barents Sea and in the north. It is an important forage fish for several marine mammals, but to some extent also for cod (Orlova *et al*., 2001). There is little fishing on this stock.

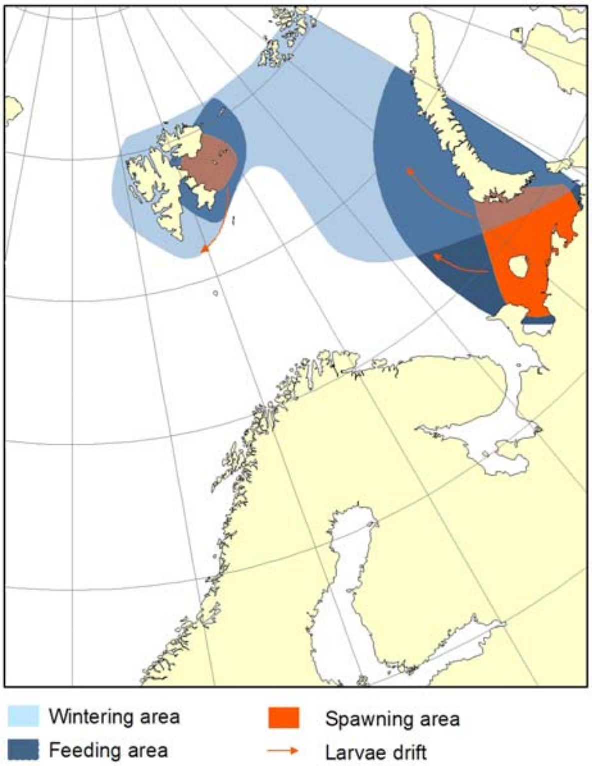


Figure 2.17. Distribution area for polar cod.

Blue whiting

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. Histroically, 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.

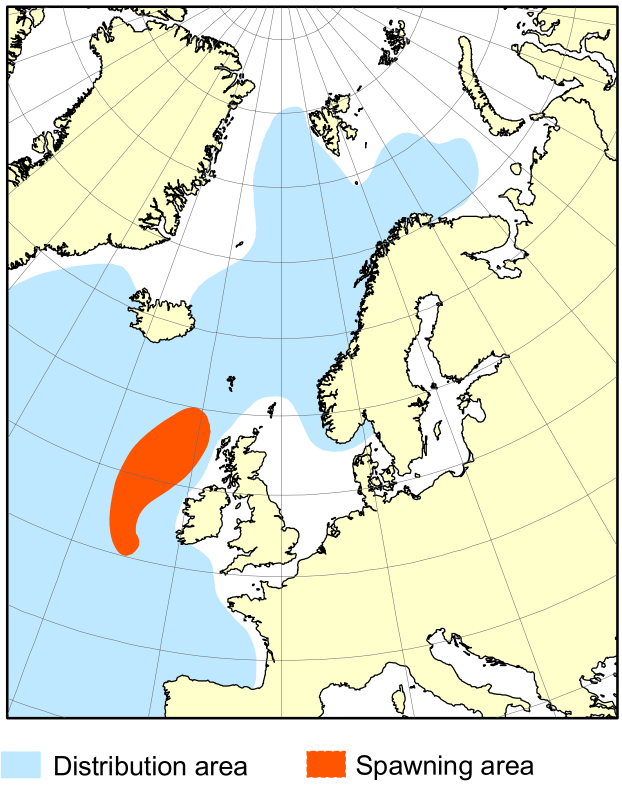


Figure 2.18. Distribution area for blue whiting.

Recruitment

The recruitment of the Barents Sea fish species has a large year-to-year variability (Figure 2.19). 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.

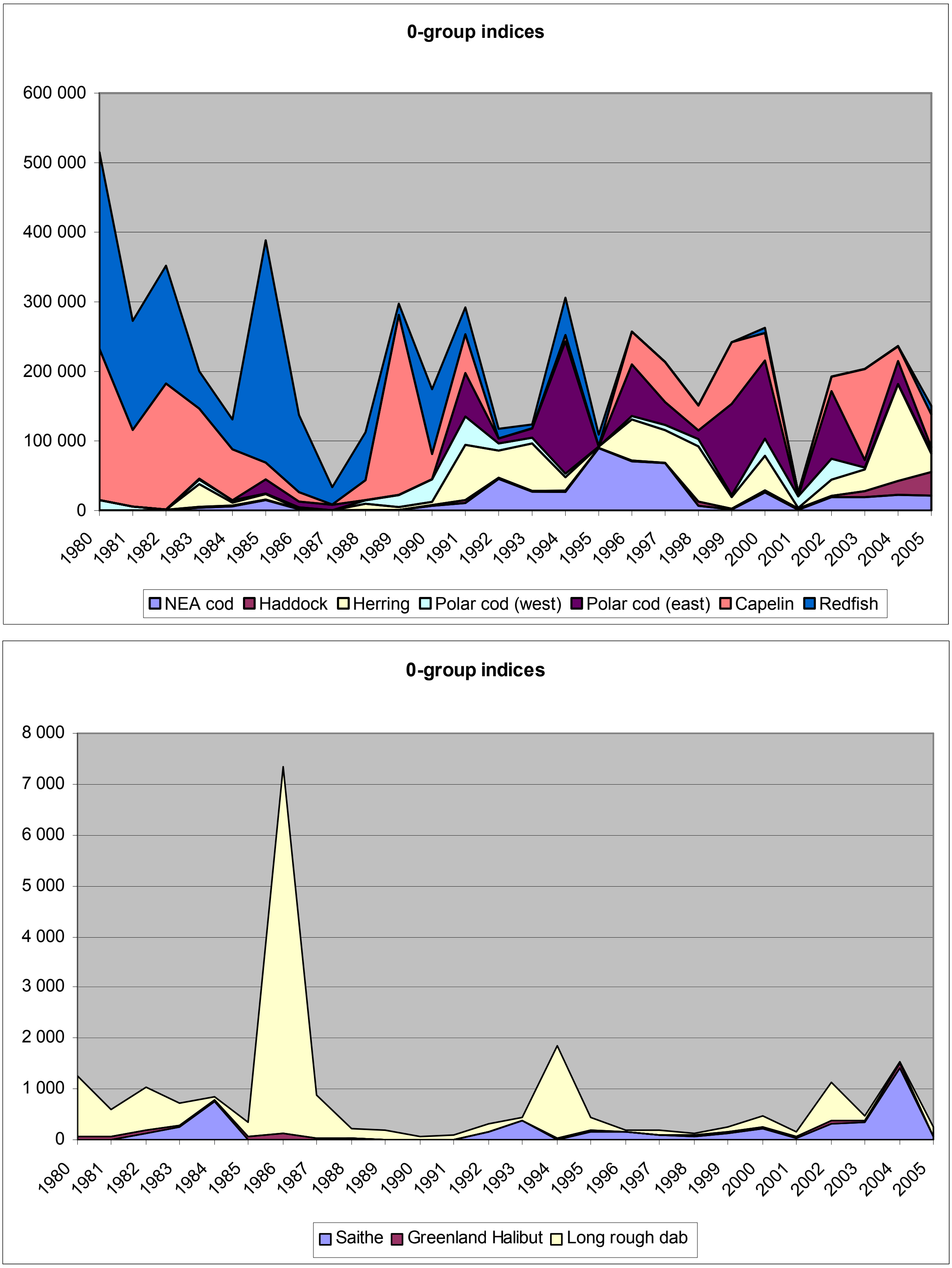


Figure 2.19. 0-group abundance indices (in millions), not corrected for catching efficiency. Please note that the vertical axes differ between the two panels.

Other fish species

Other targeted species not mentioned above include saithe, wolffish, and other flatfishes (*e.g.*, plaice, long rough dab), which are common on the shelf and at the continental slope. Saithe is found mainly along the Norwegian coast, but also occurs in the Norwegian Sea and in the southern Barents Sea. The 0-group saithe drifts from the spawning grounds to inshore waters. 2-3 years old the saithe gradually moves to deeper waters, and at age 3-6 it is found at typical saithe grounds. It starts to mature at age 5-7, and in early winter a migration towards the spawning grounds further out and south starts. Also ling and tusk are relatively common and found at the slope and in deeper waters.

In total, about 206 fish species from 65 families have been recorded in the Barents Sea (Dolgov, 2004). However, the fish community is dominated by few, very abundant species. In joint IMR-PINRO surveys, more than 100 fish species has been caught the last 25 year. In Figure 2.20, the logarithm of the total catch in bottom trawl hauls from the bottom trawl survey run in February in the Barents Seas since 1981, is plotted against species rank, from the most abundant species to the rarest. From the plot, it can be seen how a few species dominates in abundance (Figure 2.20).

The fish species in the Barents Sea occur in more or less well defined zoo-geographical species assemblages composed by species with overlapping physical habitat requirements (Ekman 1953; Zenkevich, 1963; Nilssen and Hopkins, 1992; Fossheim and Nilssen, 2002). Table 2.1 show how the 47 most common fish or fish caught in the bottom trawl at the joint IMR-PINRO ecosystem survey in 2005 correlates with depth, latitude, and longitude.

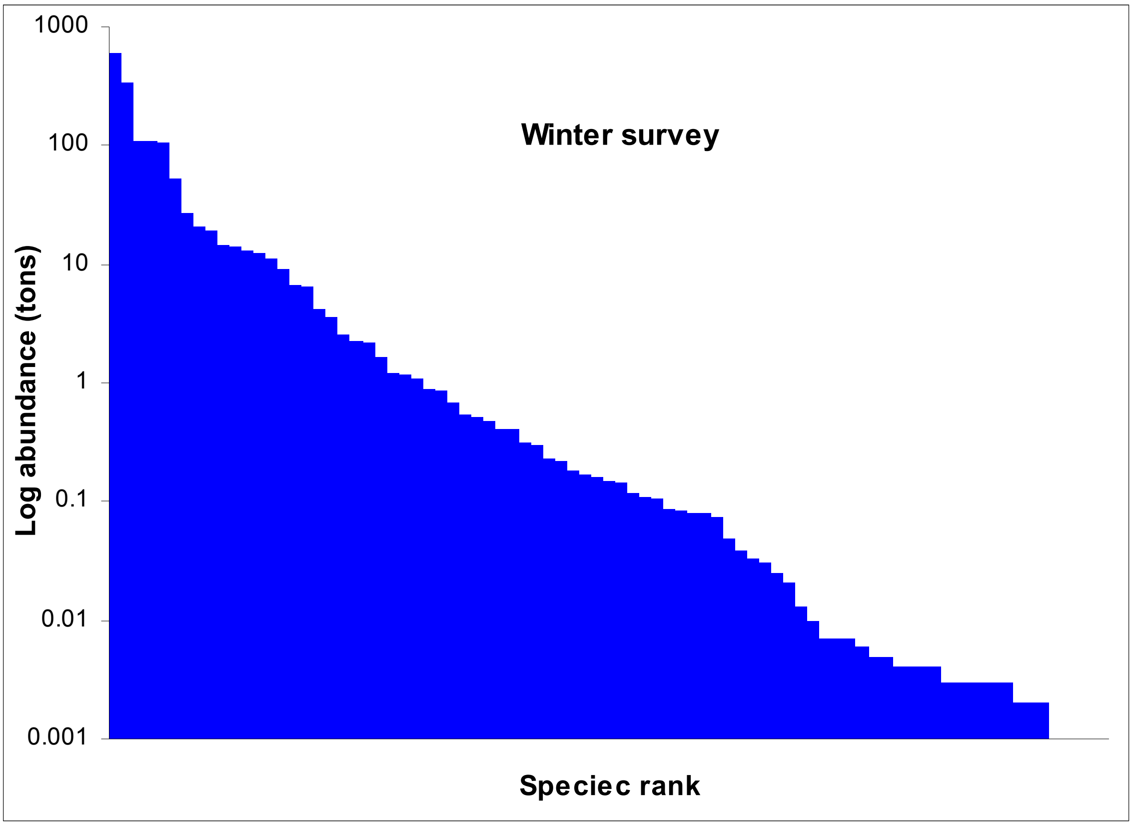


Figure 2.20. Log abundance plotted against species rank. The abundance is the total catch in tonnes from the winter bottom trawl survey run since 1981 in February.

Table 2.1. Species *found in more than ten out of 642 bottom trawl stations in the ecosystem survey 2005. The species area sorted after their abundance e.g. the total catch of each species. Correlations between depth, latitude and longitude and catch rate (kg per distance towed) of the different species are shown as 0=non-significant, -= significant negative correlation, += significant positive correlation.*

Total catch in kg	Species	Depth	Latitude	Longitude
4265	Long rough dab	-	-	+
3962	Cod	-	-	0
3100	Polar cod	-	+	+
2633	Greenland halibut	+	+	-
2058	Haddock	-	-	-
1928	*Cyclopteridae spp.*	0	+	+
1805	Thorny skate	+	-	-
1724	Deep water redfish	+	0	-
1702	Capelin	-	+	+
1676	Blue whiting	+	-	-
1588	Atlantic hookear sculpin	-	+	+
1570	*Triglops sp.*	-	+	+
1143	Atlantic poacher	-	+	+
940	Spotted snake blenny	-	+	+
810	Vahl's eelpout	+	-	-
696	*Lycodes rossi*	-	0	0
656	Snake blenny	-	0	-
558	Golden redfish	0	-	-
539	Northern wolffish	+	-	-
520	Atlantic wolffish	-	-	-
512	Norway pout	-	-	-
496	Spotted wolffish	-	-	-
435	*Lycodus pallidus*	0	+	+
381	*Lycodes eudipleurosticus*	+	+	-
361	Esmarks's eelpout	+	+	-
347	*Lycodes reticulatus*	-	+	+
324	*Cottunculus microps*	-	-	+
281	Saithe	-	-	0
271	*Arctozenus rissoi*	+	+	-
254	*Lycodes seminudus*	+	+	+
222	Twohorn sculpin	-	-	+
222	Norway redfish	0	-	-
212	Herring	-	-	+
212	Arctic staghorn sculpin	-	-	+
203	Greater argentine	0	-	-
200	Arctic skate	+	+	-
157	Rough grenadier	+	0	-
110	Cusk	0	-	-
98	Arctic alligator fish	-	-	+
98	Lumpsucker	0	0	0
94	Round ray	+	-	-
82	European plaice	-	-	+
80	*Anisarchus medius*	-	-	+
75	Arctic rockling	+	+	-
73	Spinetail ray	+	0	0
41	Bull-rout	-	0	0

2.4.4 Marine Mammals

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) 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), while harp seals are the most numerous seal in the Barents Sea with approximately 2.2 million individuals.

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).

2.4.5 Seabirds

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 the 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 to 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.

2.4.6 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 and Skjoldal, 1989; Grebmeier and 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 benthic, 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).

Red king crab (*Paralithodes camtschatica*) was introduced to the Barents Sea, the Murmansk fiord, in the 1960s. The stock is growing and expanding eastwards but more dominantly along the Norwegian coast westwards. Adult red king crabs are opportunistic omnivores. Decapods are known predators of benthic bivalves, including epibenthic species such as the commercial Iceland scallop *Chlamys islandica*. Both the red king crab and the scallop have a sub-Arctic distribution, and as the Iceland scallop has a life span of 30 years, and matures after 3-6 years, it might be particularly exposed to risk of local extinction with increasing numbers of king crabs (Jørgensen, 2005; Jørgensen and Primicerio, *in press*). No clear evidens of the king crabs impact on native bottomfauna has yet been stated in Norwegian waters, but there exist an agreement that there still is need of research on this field (Jørgensen *et al*., 2004).

Shrimp is most abundant in central parts of the Barents Sea and close to Spitsbergen, mostly on 200 – 350 meter depths (Aschan, 2000). It is common close to the sea floor, preferably silt or fine-grained sand. Shrimp in the southern parts of the Barents Sea grow and mature faster than shrimp in the central or northern parts.

2.5 Ecological relations

2.5.1 Predation by fish

Cod diet

The diet of cod is a good indicator of the state of the Barents Sea ecosystem. ***Figure 2.21*** shows the diet of cod in the period 1984-2005, 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 2005 the most important prey item for cod, followed by krill, polar cod, hyperiid amphipods, haddock, shrimp, blue whiting, herring and cod. The proportion of capelin in the diet of cod decreased from about 50% in 2003 to about 25% in 2005, but is higher than the 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. 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 individual growth of age 1 and 2 cod is below average, while it is average for older cod. The cod migrates out of the Barents Sea and spawns in the Lofoten area in March. The average age at first maturation has been declining the last decades (ICES, 2005).

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.

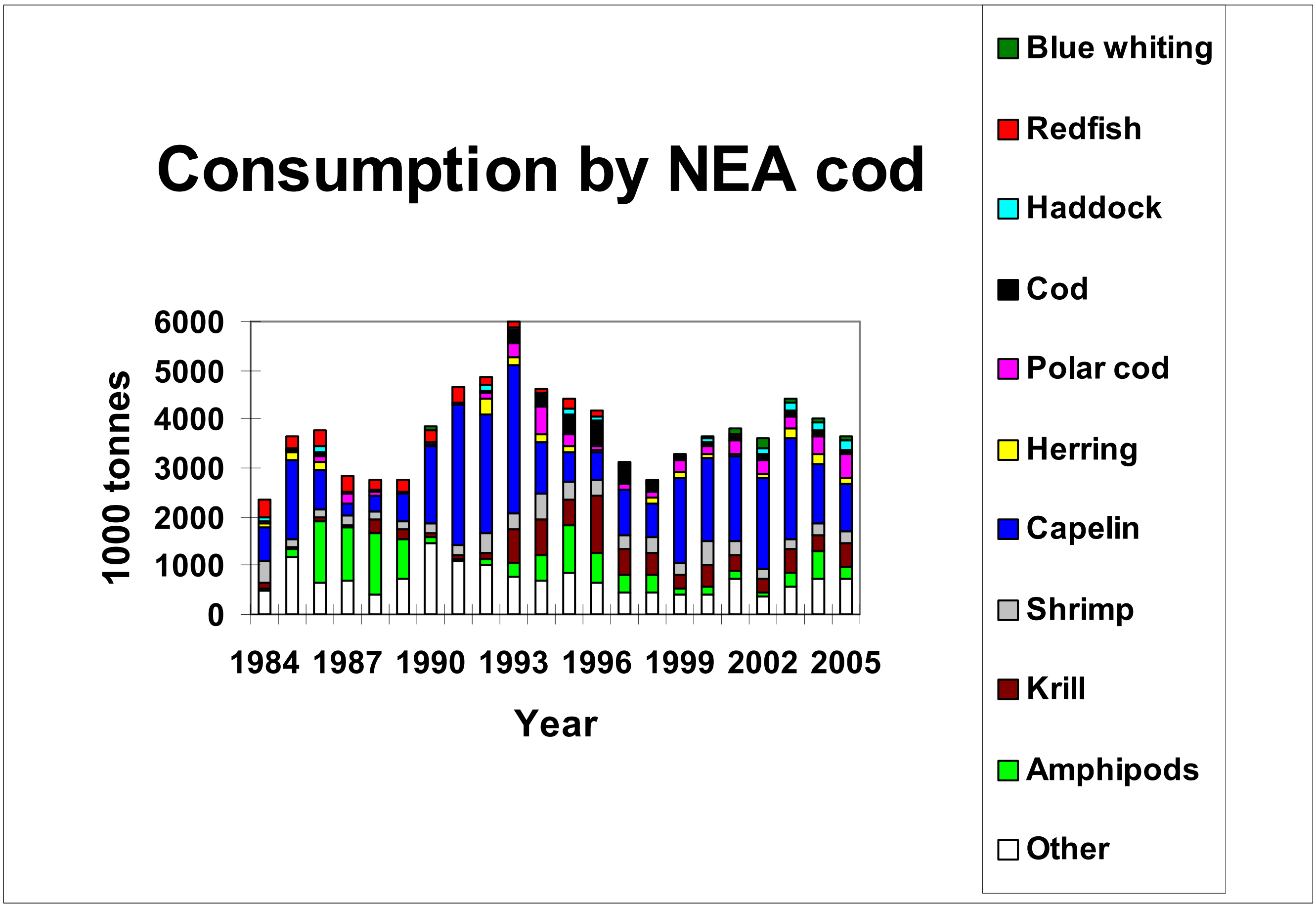


Figure 2.21. Consumption by Northeast Arctic cod in the period 1984-2005.

For cod age 3-6, the diet composition during the ecosystem survey in autumn 2005 was very variable between the areas, reflecting the difference in geographical distribution of the various prey items. Blue whiting was the dominant prey item in the south-western part, while herring, krill, shrimp and capelin dominated in the south-eastern part. In the central Barents Sea shrimp was the most important prey in a large area, while polar cod dominated in the area east of 42° E and between 73° and 76° N. North of 76° N, polar cod, capelin and hyperiid amphipods dominated.

For cod age 7-13, the diet composition during the ecosystem survey was to a large extent similar to that of age 3-6 cod. Thus, blue whiting dominated in the south-western part and polar cod, capelin and hyperiids dominated north of 76° N, and polar cod dominated in the area east of 42° E and between 73° and 76° N. Shrimp was the dominant prey item in the central Barents Sea, but over a smaller area than for age 3-6 cod. Also, the proportion of cod and haddock in the diet was high in several parts of the central Barents Sea, with cod also being an important prey west of Spitsbergen.

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, the pelagic species were the most important (i.e. polar cod, capelin, haddock, saithe and redfish). 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.

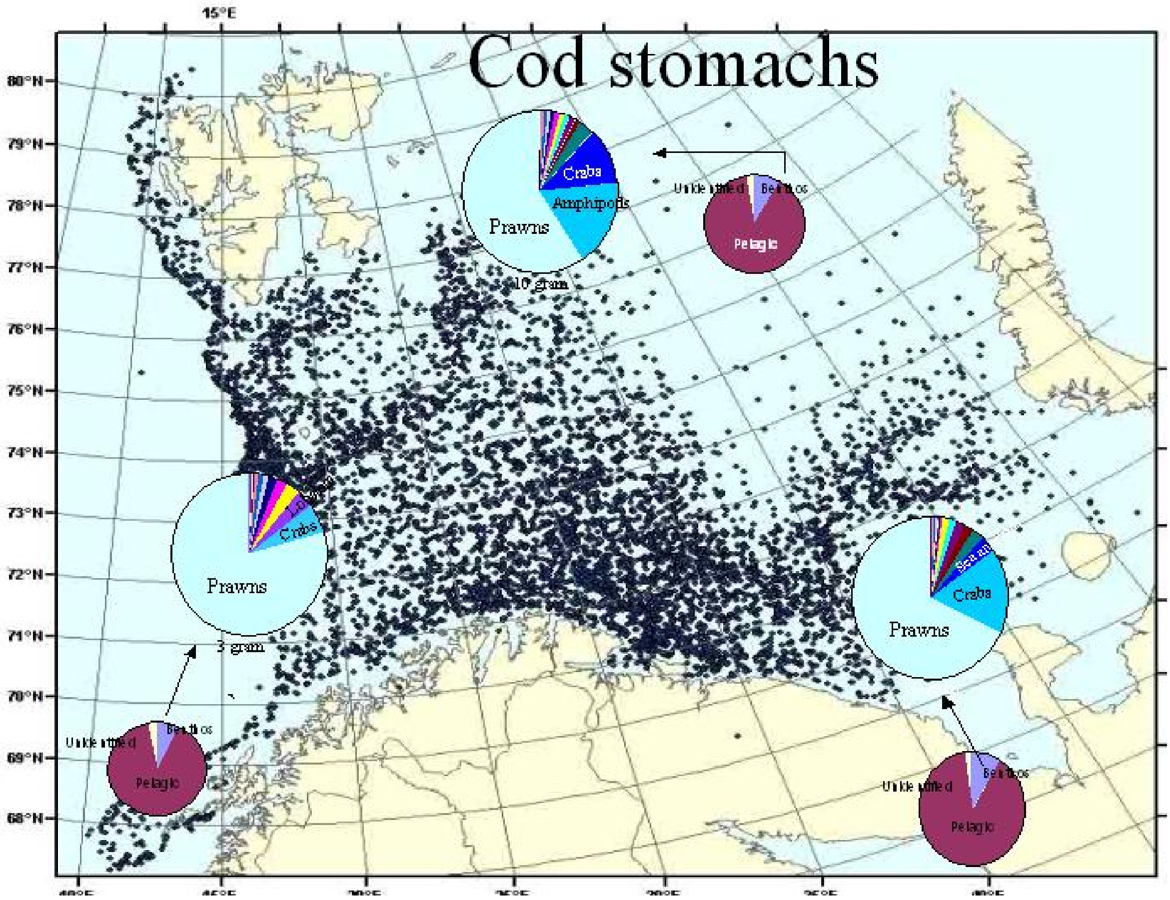


Figure 2.22. The stomach content (small reddish circles) of cod (7-11 years old) and detailed information (large bluish circles) on what animal groups (less that 10 % of total stomach content) that constitute bottom species.

Benthos-fish interactions

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 2.22) 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.

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 2.23). 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.

As 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.

Northern shrimp (*Pandalus borealis)* is an important prey for several fish species, especially cod, but also other fish stocks like blue whiting (ICES, 2005). Consumption by cod significantly influences shrimp population dynamics. The estimated amount of shrimp consumed by cod is on average much higher than shrimp landings.

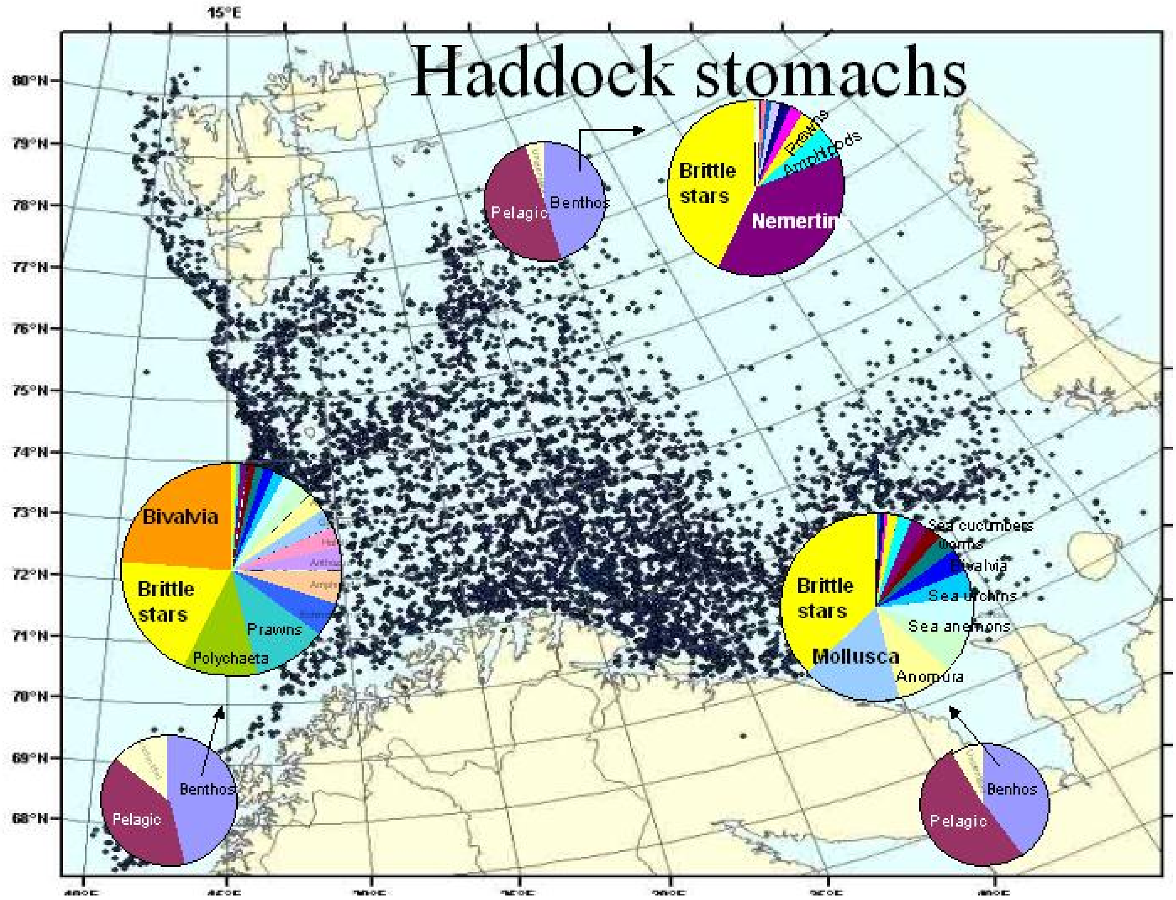


Figure 2.23. The stomach content (small reddish blue circles) of haddock (3-11 years old) and detailed information (yellow orange circles) on what animal groups (approximately 50% of the total stomach content) that constitute bottom species.

Zooplankton–capelin

Figure 2.24 show that zooplankton biomass has varied significantly between years. The annual variability may reflect the changes in predation pressure and climate.

There is a significant negative relationship between zooplankton and capelin in the Barents Sea (1 % level; $R^2 = 0.23$). Capelin is a major predator on zooplankton in the Barents Sea and is known to exploit a large portion of the secondary production during their feeding season (Gjøsæter *et al.*, 2002). This is especially true in years when the capelin stock size has been high (2-7 million tonnes). Though statistical analyses support the interdependencies of capelin and zooplankton biomass, these analyses also show that other factors may be important for determining the fate of the zooplankton biomass.

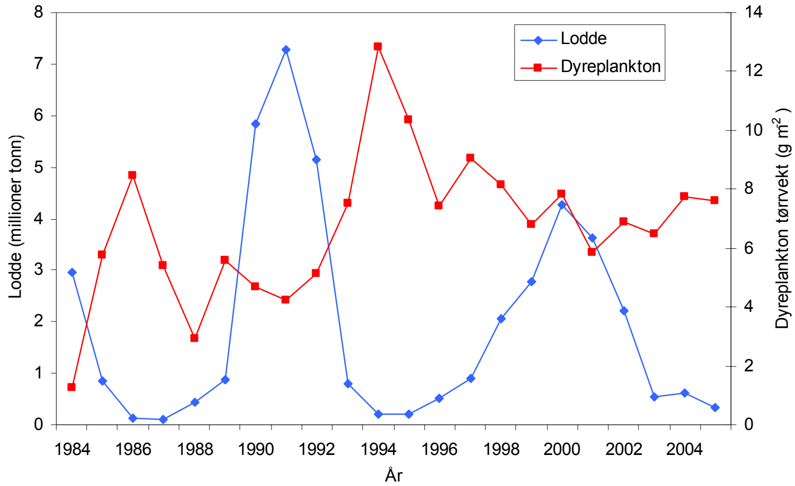


Figure 2.24. Annual fluctuations in zooplankton biomass (red curve) and size of capelin stock (blue curve) in the Barents Sea. Data on zooplankton before 1987 are from Juday net; after 1987 are from WP2-net.

Heavy predation by cod and young herring on zooplankton as well as annual fluctuations in climate and the long-time trend towards a warmer climate will likely influence these interactions (see trophic interactions in this report). A significant decline in the capelin stock was observed from 2001 to 2003, which should also result in a notably reduced predation pressure from capelin. Low predation pressure from capelin is not the only explanation for the moderate increase in average zooplankton biomass from 2001 (6.0 gm^{-2}) to 2005 (7.8 gm^{-2}) in the Barents Sea. Taken into account the effect of a warming ocean, this should favour better conditions for growth of zooplankton. Thus, it should probably be expected that the increase in zooplankton biomass would be larger as in previous years when the capelin stock was reduced. The explanation might be that other organisms due to their high abundance (i.e. juvenile herring and blue whiting) maintain a high predation pressure that does not allow a further increase in zooplankton stocks.

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 1984-2005 (ICES, 2005). 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).

2.5.2 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 programme 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 where also the distribution of 0-group fish, zooplankton, capelin and herring were recorded (Figure 2.25). As predators tend to aggregate where their prey is abundant (e.g. Fauchald and Erikstad, 2002), we expect to identify marine mammal – prey interactions as positive spatial associations between marine mammals and their preferred prey. 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 were associated with zooplankton (Mauritzen *et al*., in press). However, preliminary analyses suggest that prey selection of these species are habitat specific. For instance, while minke whales are associated with capelin in warmer Atlantic water masses, fin whales are associated with capelin along the polar front and *Lagenorhynchus* dolphins in colder waters mainly on the shelf. Hence, habitat-specific prey selection may relieve interspecific competition for the most dominating and important prey species in the Barents Sea.

The estimated consumption by minke whale (Folkow *et al.* 2000) and by harp seal (Nilssen *et al.,* 2000) is given in Table 2.2. These consumption 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.

Table 2.2. 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)	Harp seal consumption (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 relevant 'other' group for this predator.
[2] only Parathemisto

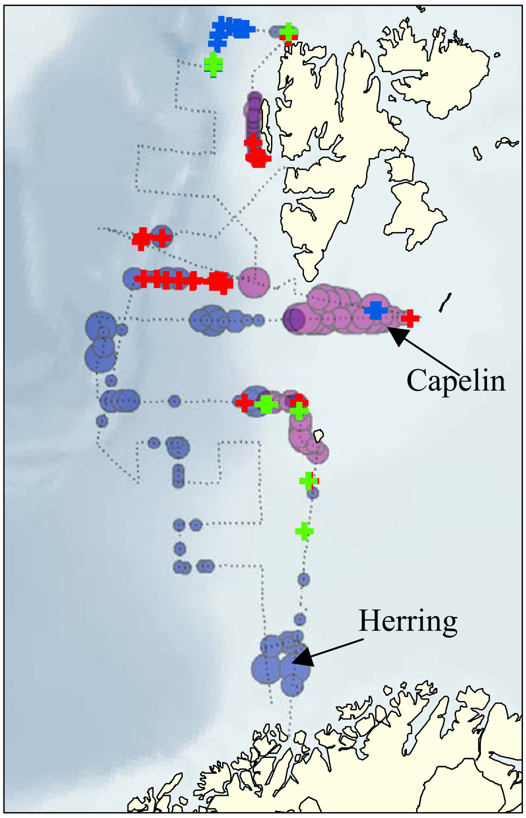


Figure 2.25. Distribution of minke whales (red circles), fin whales (blue circles) and Lagenorhynchus dolphins (green circles) relative to capelin and herring distributions as observed in August 2001.

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. In 1992-1997, minke whales may have consumed 230 000 t and 74 000 t, corresponding to 14.6 billion and 2.8 billion individuals of the herring year classes of 1991 and 1992, respectively. The dietary importance of herring to whales appeared to increase in a non-linear relation with herring abundance.

3 Monitoring of the ecosystem

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 are 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.

3.1 Standard sections

Some of the longest ocean time series in the world are along standard sections (Figure 3.1) 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 3.1. Specific considerations for the most important sections are given in the following text.

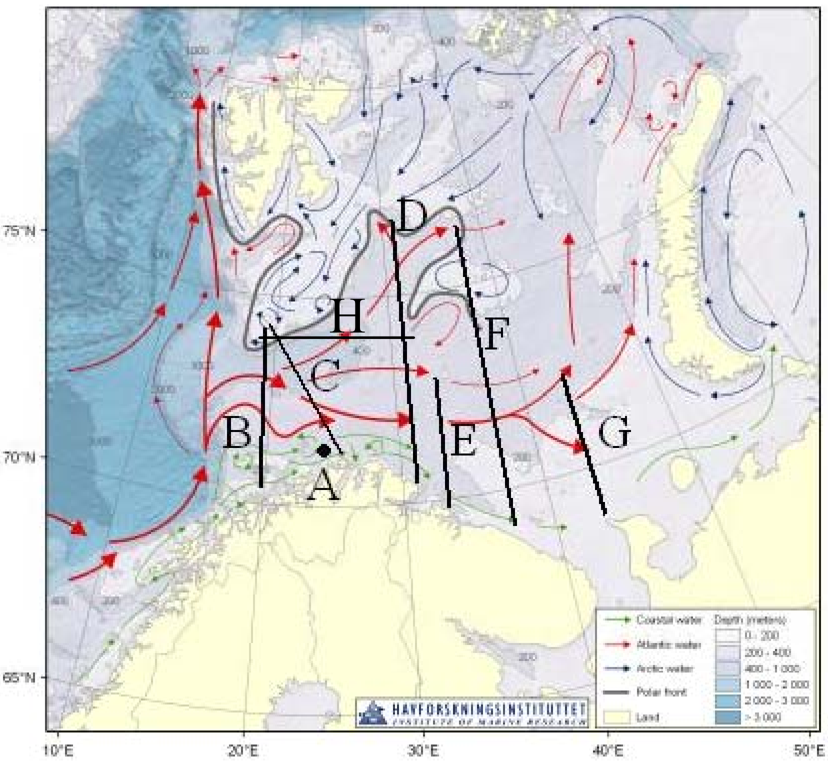


Figure 3.1. Positions of the standard sections monitored in the Barents Sea. A is fixed station Ingøy, B is Fugløya-BearIsland, C is North cape-Bear Island, D is Vardø-North, E is Kola, F is Sem Island-North G is Kanin section and H is Bear Island-East section.

Table 3.1. 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

3.1.1 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.

3.1.2 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.

3.1.3 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.

3.1.4 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.

3.1.5 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.

3.1.6 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.

3.1.7 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.

3.2 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.

3.3 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 3.2. Specific considerations for the most important surveys are given in the following text.

Table 3.2. 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**	**-**	**-**
Norwegian Greenland halibut survey	**IMR**	**Aug**	**-**	**-**	**-**	**-**	**Greenland halibut, redfish**	**-**	**-**

3.3.1 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.

3.3.2 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.

3.3.3 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 of the abundance of the youngest 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 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. From autumn 2003 onwards the saithe- and coastal cod surveys were combined.

3.3.4 Joint ecosystem autumn survey

The survey is carried out from early August to early October, and covers the whole Barents Sea. Five vessels are normally 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). The survey has developed from joint surveys on capelin and juvenile Greenland halibut, through general acoustic surveys including observations of physical oceanography and plankton, gradually developing into the ecosystem survey carried out in recent years. The predecessor of the survey dates back to 1972 and has been carried out every fall since.

3.3.5 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.

3.3.6 Norwegian Greenland halibut survey

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

3.4 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.

3.5 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.

3.5.1 Monitoring divided by ecosystem components

Climate

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

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. 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 the chlorophyll concentration, which is a measure of the phytoplankton production, analyses in 2005 included species composition. In addition to observations, the primary production is simulated using numerical models.

Zooplankton

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 will be prepared at a joint meeting held at IMR in May 2006. This will hopefully allow future exchange of biomass and species composition data between PINRO and IMR.

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.

Fish

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

Abundance and distribution of some marine mammal species in the Barents Sea are regularly monitored. Sighting surveys of cetaceans provide abundance estimates every 6 years, while harp and hooded seal abundances in the Greenland Sea are monitored every 5 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.

Benthos

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.

4 Current and expected situation of the ecosystem

4.1 Overview of state and expected situation

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. 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. 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 2005.

Phytoplankton and Zooplankton

The spring bloom of phytoplankton was late in 2005. Total zooplankton biomass was below average, but with lager spatial variations than in 2004.

Fish

The cod stock was estimate to remain at a relatively stable level in 2005 with a SSB somewhat above the precautionary approach level Bpa (i.e. having full reproductive capacity), but being exploited with an unsustainable fishing mortality (well above Fpa). The 0-group index was slightly above average level. The stock of haddock was estimated to decrease a little in 2005 but was well above Bpa with a 0-group index among the highest in the time series. However, the fishing mortality was somewhat above Fpa. There was a small increase in the survey indices of redfish in 2005 but they are all still at a historically very low level. The estimated stock size of Greeland halibut also remained stable in 2005 with a small increase in fishing mortality, and a 0-group index below average. Among the pelagic species, the acoustic abundance index of capelin continued to decrease and the probability of having a SSB below the limit value for catch recomandation (Blim) in 2006 was estimated to be high. The 0-group index was at or below average level. The estimated stock size of herring increased in 2005 and was well above Bpa, the fishing mortality was below Fpa, while the 0-group index was below average level. The polar cod acoustic abundance index also increased in 2005 and the 0-group indices were somewhat above average level.

Mammals

In 2005 concentrations of marine mammals, especially humpback whales and dolphins, at sites of high potential food aggregations were more dense and prolonged than in the previous two years. Some changes in distribution were evident as fin and humpback whales in 2005 mainly were observed in the northern areas in association with capelin and polar cod, and minke whales formed aggregations off the Murman coast probably connected to presence of capelin and herring. Surveys conducted in 2005 at the harp seal whelping and moulting grounds indicate a decrease in harp seal abundance in the Barents Sea.

Long-term trends

According to ACIA (Arctic Climate Impact Assessment, ACIA 2005) the air temperature in the world is expected to increase by 1-2 ^{o}C during the next 100 year. An important assumption for this prediction is a continuing increase in the CO2 outlet to the atmosphere at a rate giving a doubling of the CO2 level in 100 year compared with today's level. For the Arctic region the effect is assumed to be higher, with air temperatures increasing between 2-7 ^{o}C. This is mainly associated with the connected retreat of the ice cover. In the summer the ice cover may disappear, but the effect in the winter is not expected to be so drastic. However, ice habitat species may suffer dramatically under such circumstances. In the Barents Sea the water temperature is expected to increase by 1-2 ^{o}C throughout the water column.

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 4.1 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.

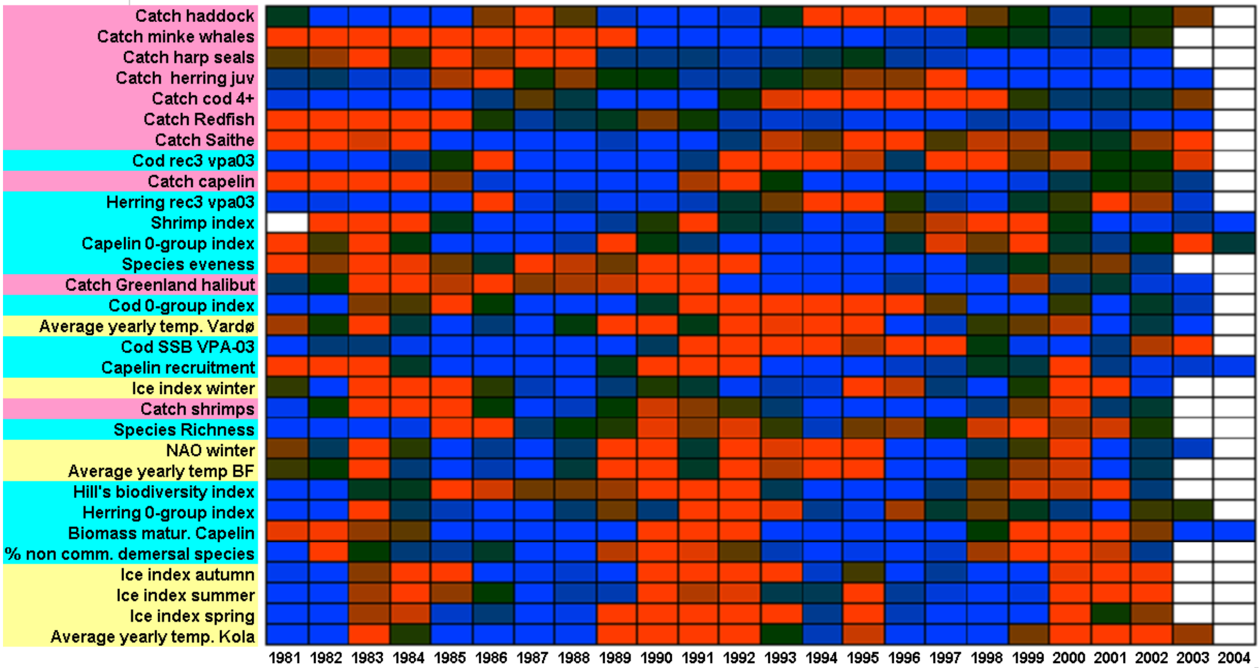


Figure 4.1. Normalized time series from the Barents Sea Ecosystem 1981 to 2004. Blue color is negative deviation and red colour is positive deviations. The colouring of the names on the left side reflect type of time series; Red is catch, yellow is climate and green is other biological time series.

4.2 Climate

4.2.1 Atmospheric conditions

The cyclonic activity had a large impact on the weather over the sea in 2005. An increase of the Icelandic Low activity took place in the beginning and end of the year. In January/February southerly winds and in the spring month's easterly and northeasterly winds predominated, and in June-December southerlies and southeasterlies prevailed. The number of storm days (wind speed is 15 m/s and more) exceeded the long-term mean in the winter-spring months, except in January when storm activity was weaker than usual. In the summer the number of storm days was close to the long-term mean values, while in the autumn the long term means were exceeded by 3-10 days as a result of the increase in cyclonic activity.

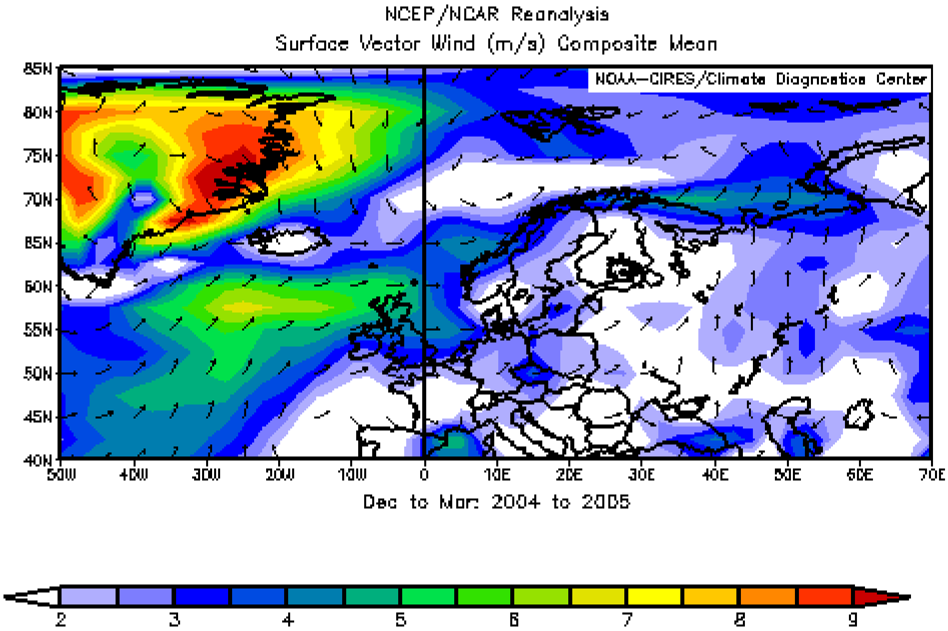
In winter 2004/2005, there were, in addition to the Icelandic low centered in the area west of Iceland, an secondary low stretching from east of Iceland deep into the Barents Sea (Figure 4.2). Such an air pressure pattern would have strengthened the southwesterly winds and increased transport of warm air and water in the southern Barents Sea. In summer 2005, horizontal air pressure contrasts were considerably smaller than in winter, and weak southerly winds prevailed over the Barents Sea (Figure 4.3). In winter 2005/2006 (Figure 4.4), main features of air pressure field over the Northeast Atlantic, Norwegian and Barents Seas were similar to those of the winter 2004/2005. However, air pressure over the Barents Sea was in general slightly higher.

Air temperature exceeded the long-term mean during the whole year. Maximum positive anomalies of air temperature (up to 6.0-7.0°C) took place in January/February. Slightly negative air temperature anomalies were registered only in the eastern sea in June/July (Figure 4.5).

Table 4.1 summarizes air temperature anomalies at some weather stations at the western and southern Barents Sea during the period from late 2004 through 2005 and into early 2006. In winter 2004/2005 air temperature over the region was considerably warmer-than-normal (by 2.0-5.0 °C), with highest anomalies (5.7-7.9 °C) at Spitsbergen airport. March 2005 was colder-than-usual at all stations. During April-October temperature anomalies were predominantly positive but considerably smaller than in winter. During late autumn and winter 2005/2006 (November-February) positive anomalies rose again compared to summer months. In the southern part of the sea (Vardø, Murmansk and Kanin Nos), air temperature was warmer-than-normal by 0.2-5.7 °C, while in the northwestern Barents Sea (Spitsbergen airport and Bear Island) positive anomalies ranged from 3.2 °C to 12.0 °C. Mean annual air temperature in 2005 was warmer-than-average by 1.5-2.5 °C. At stations Bear Island, Vardø and Murmansk it was close to the highest on record values. At Spitsbergen airport air temperature was highest on record (1977-present time).

Table 4.1. Mean air temperature anomalies at weather stations around the Barents Sea in December 2004 – February 2006, yearly mean anomaly in 2005, maximum anomalies and years when they were observed.

Station	Year/Month															2005 mean	Max/ Year
	2004	2005												2006			
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb		
Spitsbergen airport	5.7	7.2	7.9	-3.2	1.6	2.2	1.8	0.9	1.5	-1.0	-0.1	5.2	8.5	12.0	5.0	2.5	1.7 1999
Bear Island	4.9	4.8	4.6	-1.2	2.2	0.9	1.1	1.1	1.1	0.3	0.8	3.2	5.1	7.2	3.4	2.0	2.1 1954
Vardø	2.5	2.3	1.6	-1.0	0.9	1.0	1.7	0.9	1.8	0.8	2.4	3.5	2.1	2.2	0.1	1.5	1.5 1937
Murmansk	4.1	3.8	2.8	-2.3	0.7	0.6	1.8	0.6	2.2	1.3	3.4	5.7	1.4	3.6	-0.9	2.0	1.9 1937
Kanin Nos	-0.3	3.5	3.3	-2.3	-0.3	1.2	0.4	-0.2	2.8	2.0	3.3	4.5	2.2	0.2	-	1.5	2.5 1937



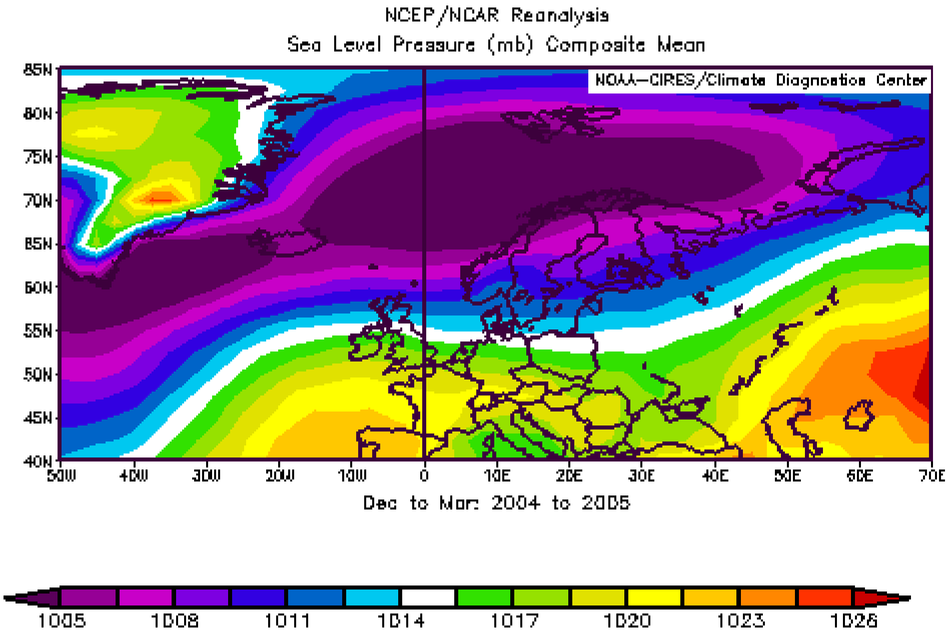
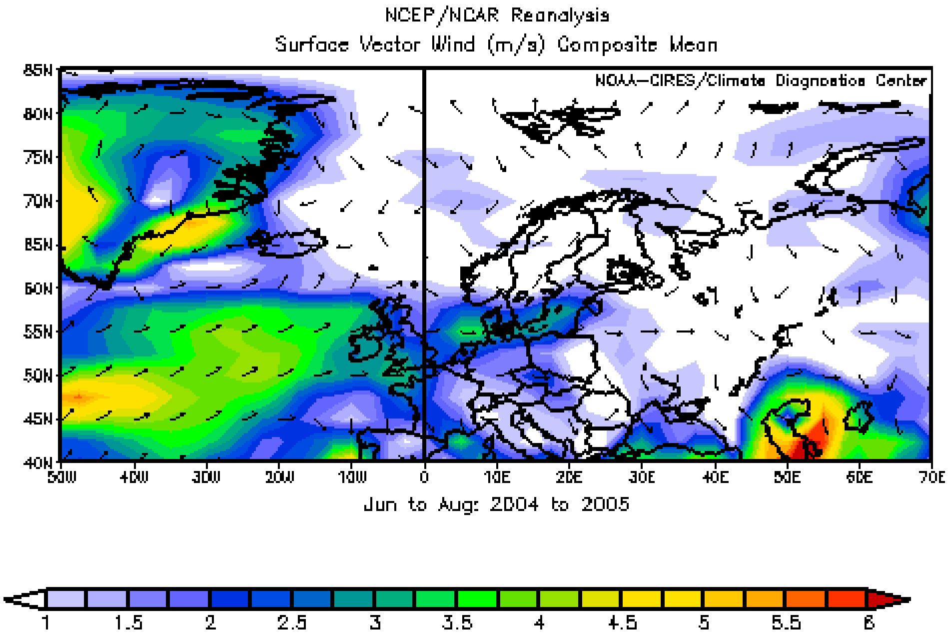


Figure 4.2. Sea level pressure (above) and wind vectors (below) in December-March 2004-2005.



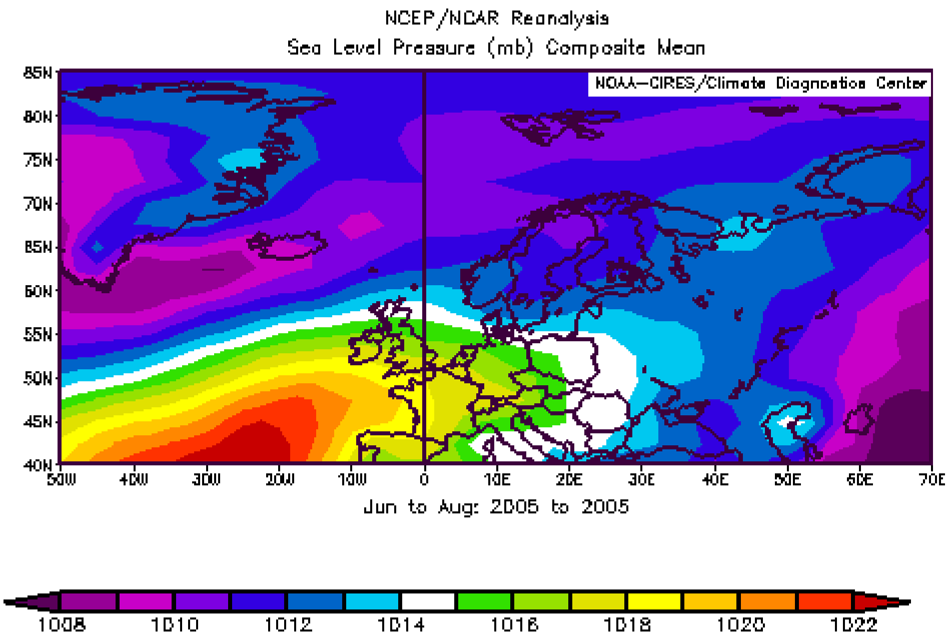


Figure 4.3. Sea level pressure (above) and wind vectors (below) in June-August 2004-2005.

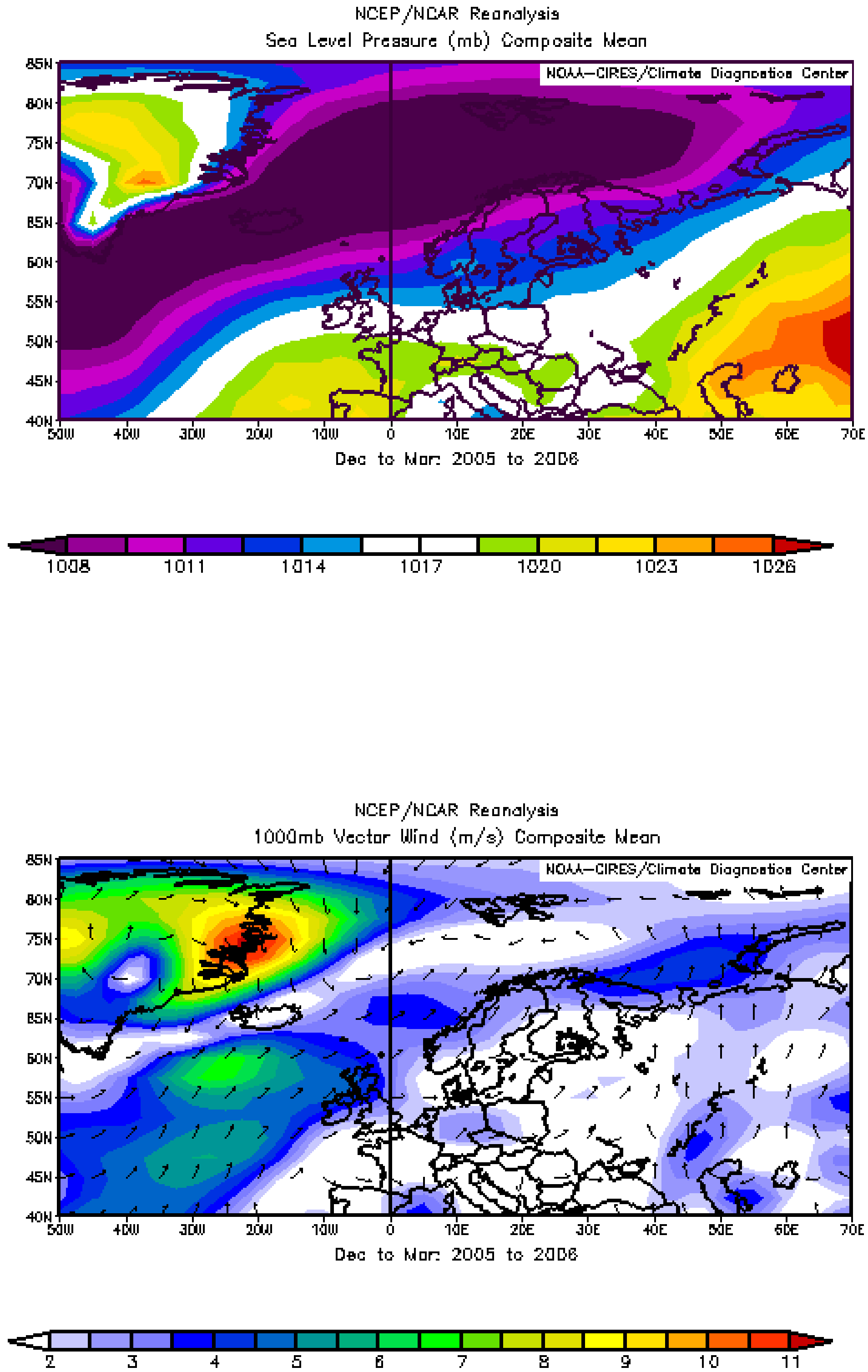


Figure 4.4. Sea level pressure (above) and wind vectors (below) in December-March 2005-2006.

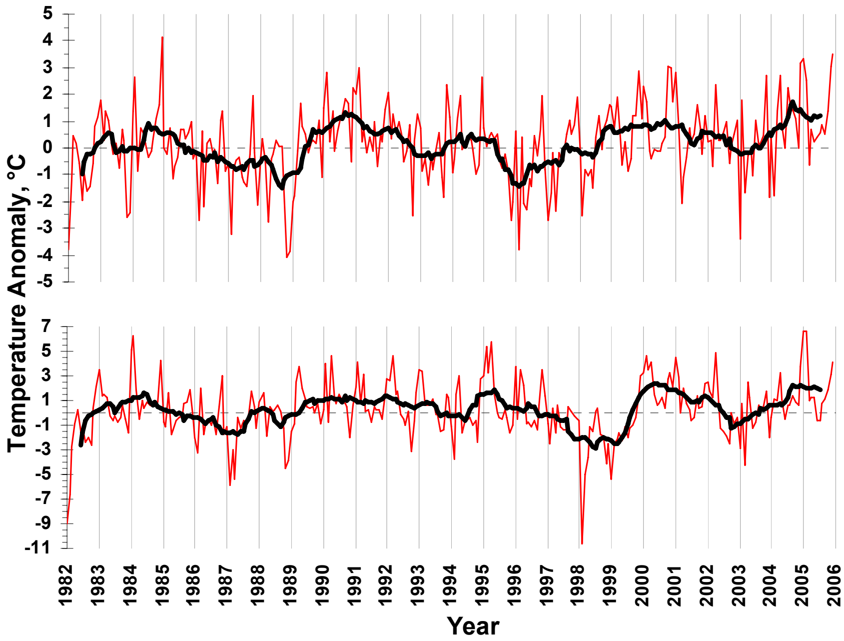


***Figure 4.5. Air temperature** anomalies in the western (upper) and eastern (lower) Barents Sea for the period 1982-2005. (from Anon., 2006a).*

4.2.2 Hydrographic conditions

In general the Barents Sea experienced one of the warmest years ever observed in 2005. Several all-time-high temperatures were recorded in the various sections. In the beginning of the year the temperature in the southern Barents Sea was close to the seasonal maximum observed with anomalies of about 1°C above the long-term mean. This situation continued until June, when the temperature decreased somewhat, but still remained about 0.5°C above the long-term mean. In November the temperatures rose towards seasonal maximum observed values again (positive anomalies of around 1°C, and remained at this high level for the rest of 2005.

Figure 4.11 shows the observed horizontal temperature field at 100 m depth in August/September 2005. Both the model and the observations show the general high temperature, especially in the southern Barents Sea. In the summer of 2005 there were high temperatures in the Hopen Trench, while along the coast the temperatures were moderate. This was probably due to the southeasterly wind field dominating during summer that caused a more northerly distribution of Atlantic Water. This is also consistent with the temperature anomalies in the Fugløya-Bird Island, Vardø-N and Kola-sections. In the near-bottomn layer the temperature was warmer than normal nearly all over the Barents Sea in August/September 2005 (Figure 4.12).

Figure 4.7 shows the temperature and salinity anomalies in the Fugløya-Bear Island section in the period from 1977 to October 2004. Temperatures in the Barents Sea were relatively high during most of the 1990s, and with a continuous warm period from 1989-1995. During 1996-1997, the temperature was just below the long-term average before it turned warm again at the end of the decade. Even if the whole decade was warm, it was only the third warmest decade in the 20th century (Ingvaldsen *et al*., 2003). Rounding the millennium there was a short period in 2000-2001 when the temperatures were close to the long-term mean. Thereafter they gradually increased to a record-high value of 1.12^{o}C above the long-term mean in January 2005. During spring and summer the temperatures decreased to about 0.5 ^{o}C above the mean, but in autumn 2005 they again increased towards a new record-high temperature of 1.44 ^{o}C above the mean in January 2006. In the spring and summer of 2006 the temperatures decreased, but is still more than 1 ^{o}C above the long-term mean.

The Vardø-N section show in general much the same pattern as the FB-section, except that the period after the millennium with temperatures close to the long-term mean was in 2001-2002 (Figure 4.8). Thereafter there was a rapid increase in temperature, and in January 2005 the temperature was 1.2°C above the long-term mean. However, the three most northern stations were not sampled on this survey, which means that this temperature estimate is too high compared to earlier years. As for the FB-section the decreased somewhat during the summer of 2005, but then increased towards a record-high value of 1.33 ^{o}C above the long-term mean in January 2006.

The monthly temperature time series from the Russian Kola section (33°30' E, 70°30'N to 72°30'N) begins in 1921, but quarterly values back to 1900 exist. Figure 4.9 shows the yearly development since 1951 and Figure 4.10 the seasonal development in 2005 along with the average values (Anon., 2005). The values were calculated by averaging along the transect and from 0 to 200 m water depth vertically (Bochkov, 1982, 2005). The Kola section is strategically placed to monitor the variability in the temperature of the eastern part of the Barents Sea dominated by inflowing Atlantic water masses. The temperature in the Kola section was between 0.6 and 1.0°C above the long-term seasonal mean (1921-1999) in 2005. The temperature in August was the highest observed for this month (5.73°C which is 1.06°C above the long-term mean). In 2005 the temperatures stayed high, but no record-high values were observed like in the FB- and Vardø-N sections. However, due to relatively high temperatures throughout the summer, the annual mean temperature for 2005 is the highest recorded.

The salinity in the Fugløya- Bear Island section generally fluctuates in phase with the variation of the temperature (Figure 4.7). This is also the situation in the rest of the Barents Sea, which is influenced by the Atlantic waters. Since the summer of 2003 there has in general been increase in the salinity in the southwestern Barents Sea.

The temperature in the coastal water entering the Barents Sea was in general 0.5-2 ^{o}C higher than the long-term mean (Figure 4.6) throughout 2005. Only at a few occasions the temperatures were at or just below average, and then only for specific depths. The highest anomalies were observed in the beginning and end of the year, with the highest values observed in November, with a positive anomaly of about 2^{o}C. However, the temperatures could show large variations within one month. The salinity was in general within the normal values (i.e. within 1 SD of the mean), but mostly lower than average.

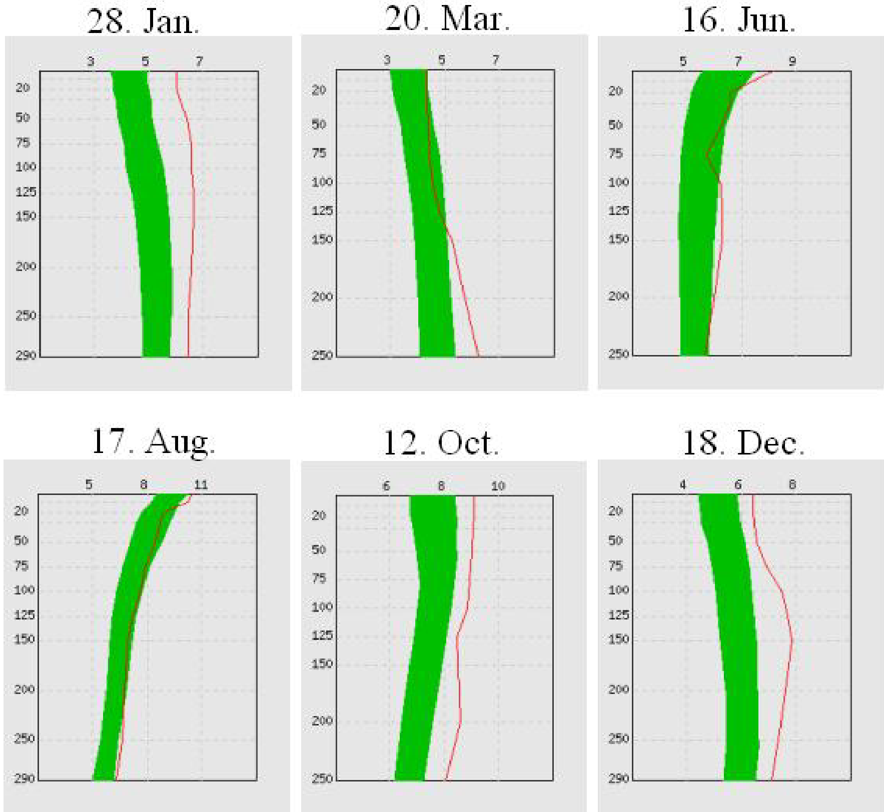


Figure 4.6. Temperature profiles at different dates throughout 2005 at the fixed station Ingøy, northern Norway, situated in the coastal current at the entrance to the Barents Sea. The green areas are the typical variations, +/- one SD of the long term average for the combined period 1936-1944 and 1968-1993). The red line is the observed profile at the given date in 2005.The vertical axis is depth (m) and horizontal axis is temperatures (^{o}C)

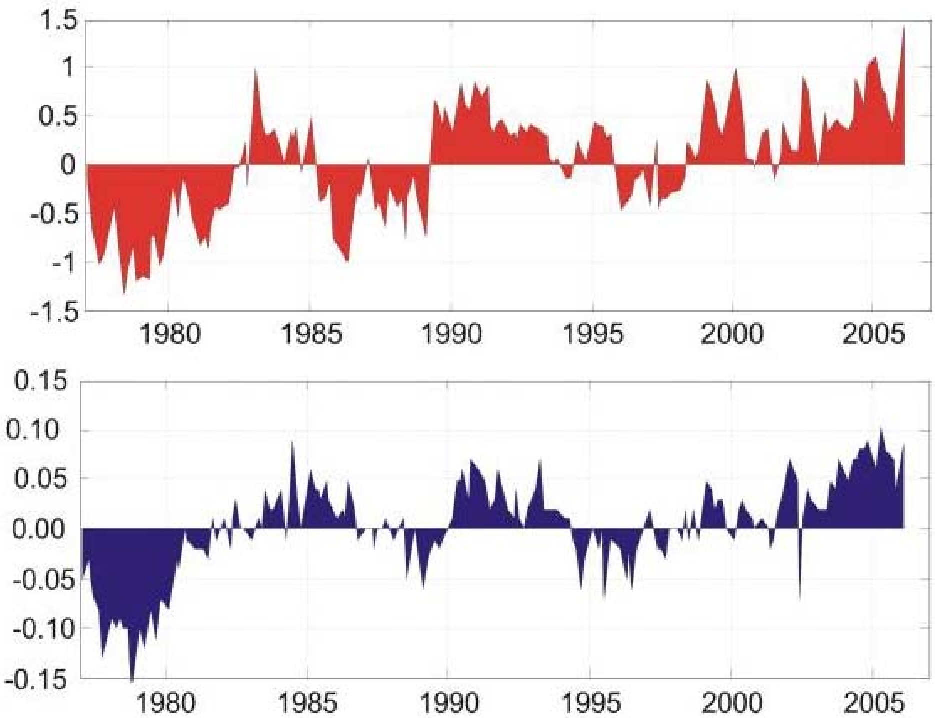


Figure 4.7. Temperature anomalies (upper panel) and salinity anomalies (lower panel) between 50 and 200 m depth for the period 1977-2005 in the section Fugløya – Bear Island.

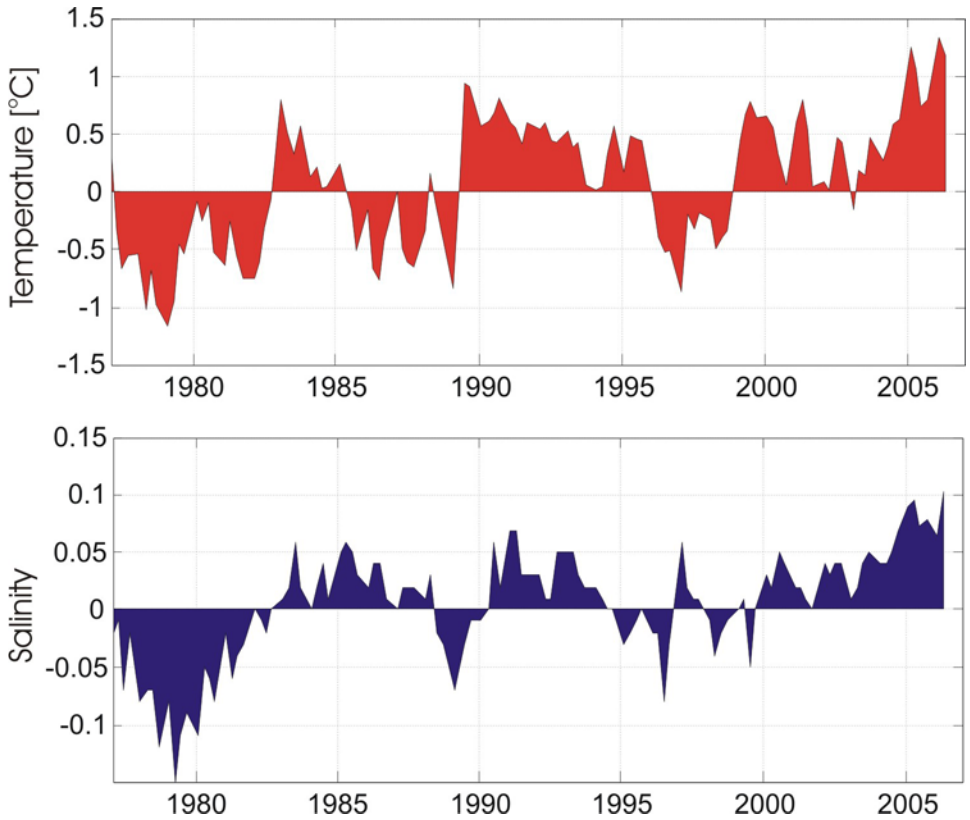


Figure 4.8. Temperature anomalies (upper panel) and salinity anomalies (lower panel) between 50 and 200 m depth for the period 1977-2005 (including March 2006) in the section Vardø-N.

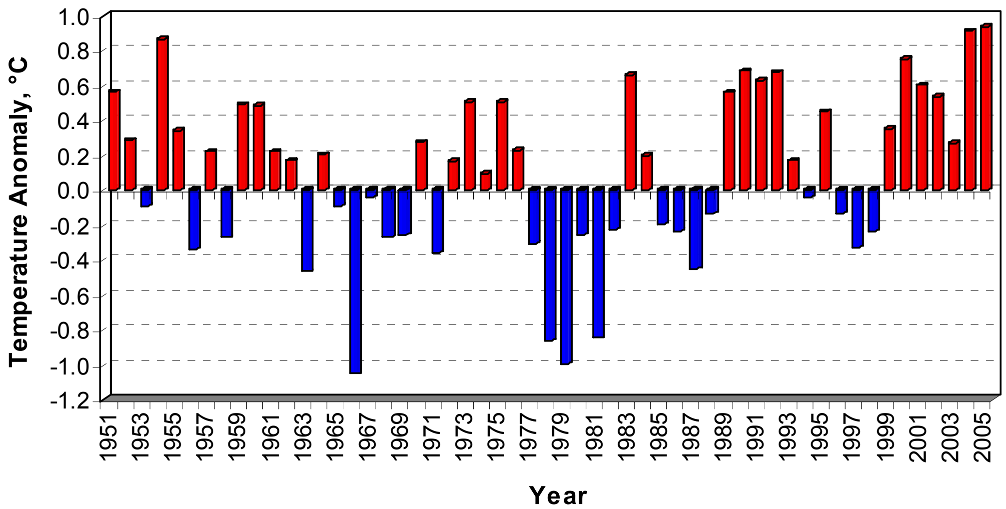


Figure 4.9. Annual mean temperature anomalies in the 0-200 m layer in the Kola Section for the period 1951-2005 (Anon., 2006a).

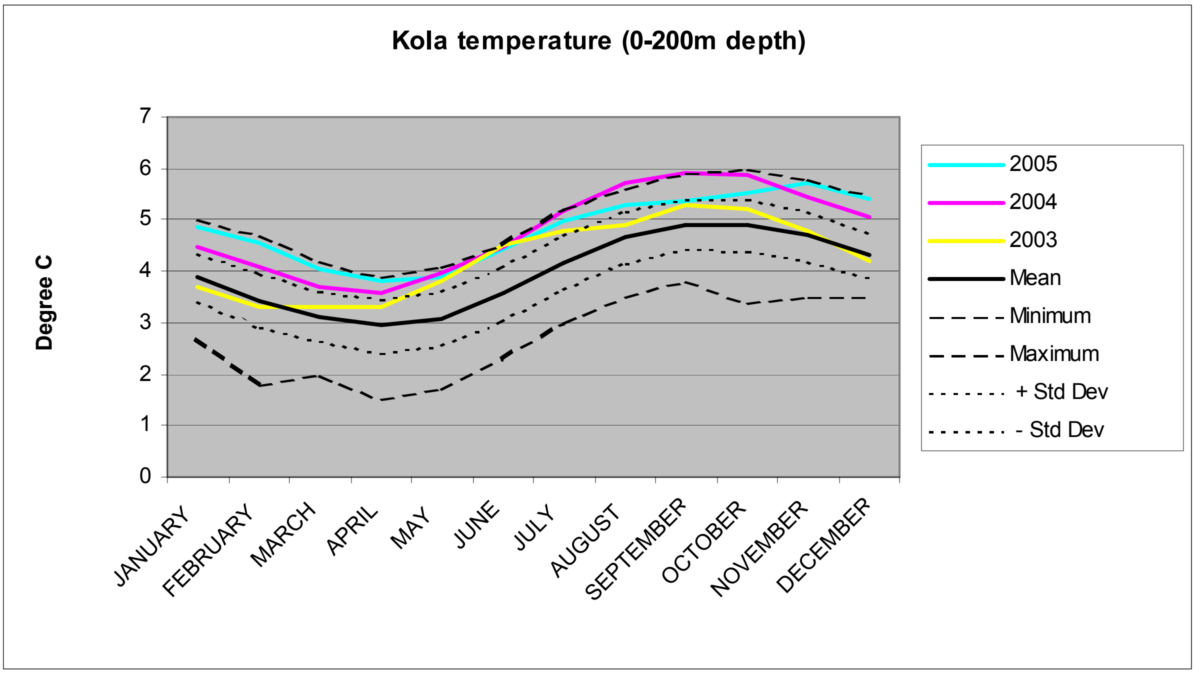


Figure 4.10. Monthly temperature development in the Kola section. The figure shows temperature statistics (long-term seasonal mean, minimum, maximum and standard deviations) for the period 1921-1999, together with the values for 2003-2005, given for each calendar month for the 0-200 m depth interval.

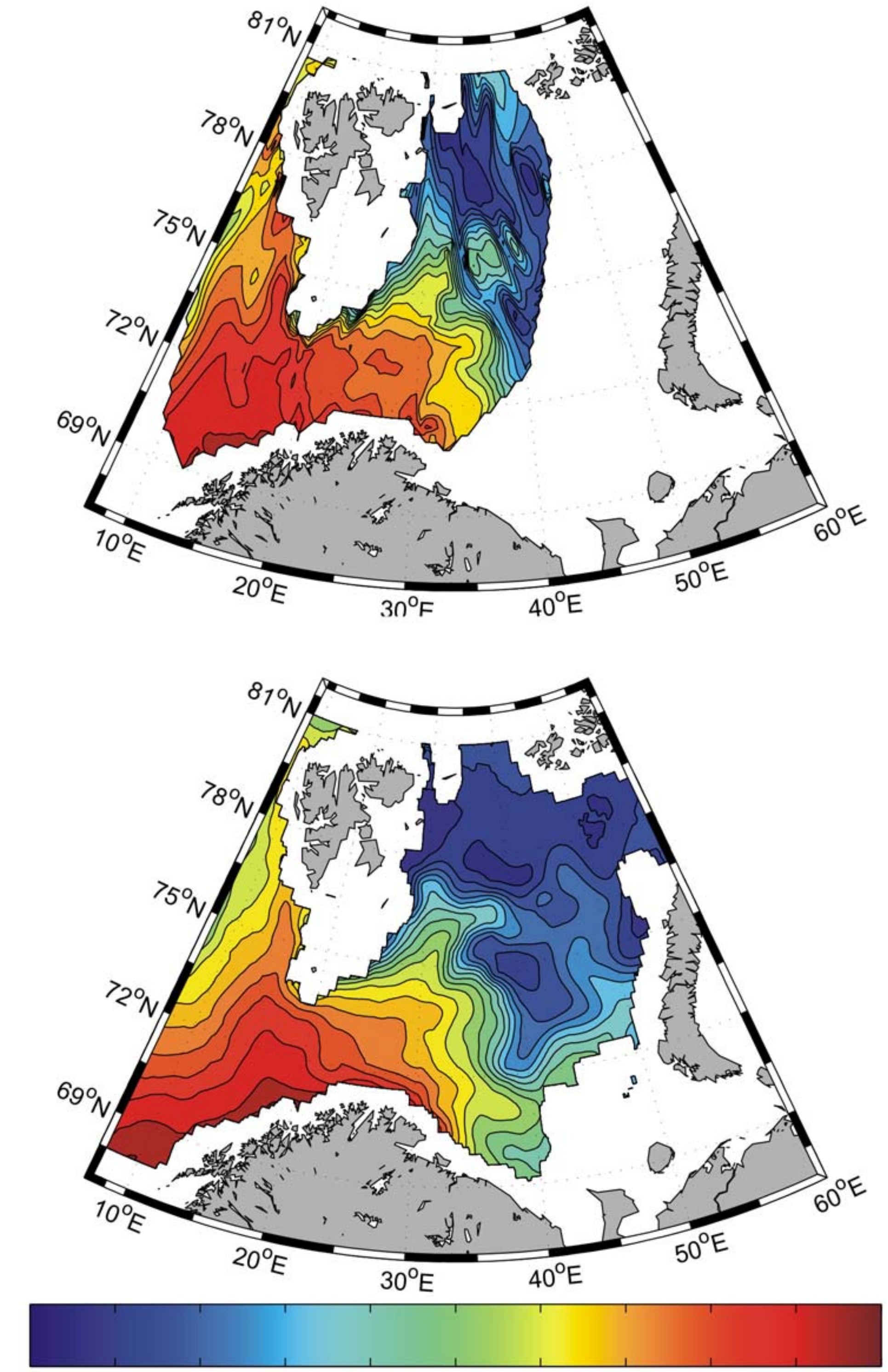


Figure 4.11. Distribution of mean temperature at 100 m depth during August–September. Upper panel: 2005. Lower panel: mean temperature.

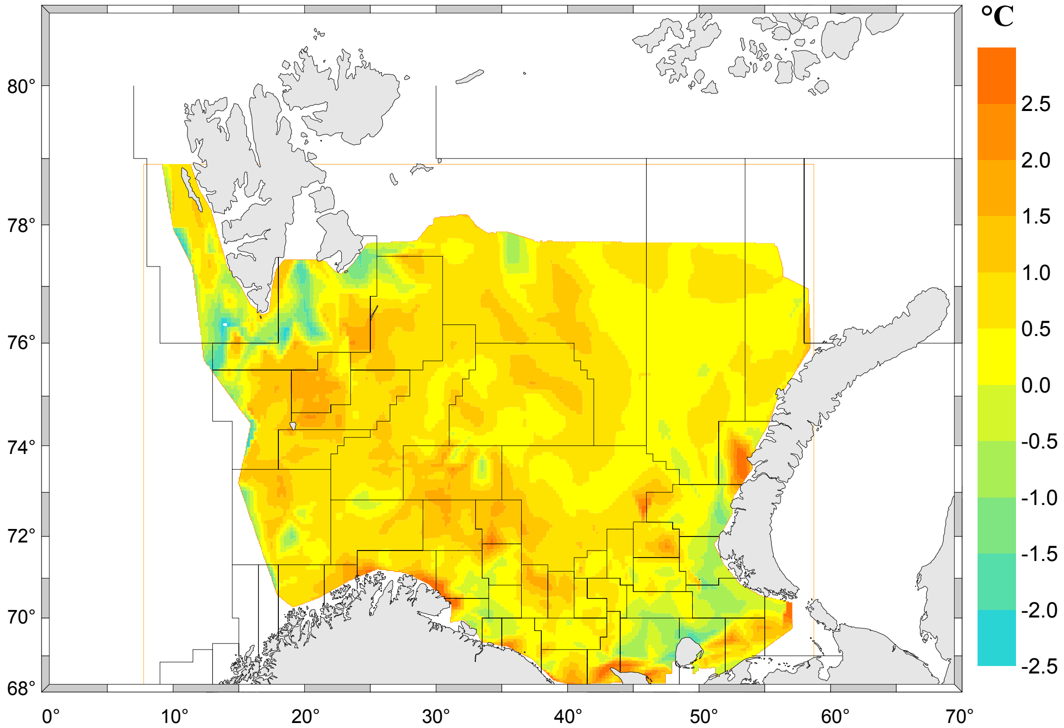


Figure 4.12. Bottom temperature anomalies in August-September 2005.

4.2.3 Currents and transports

The time series of volume and heat transports reveal fluxes with strong variability on time scales ranging from one to several months (Figure 4.13). In 2005 the inflow of Atlantic water from the Norwegian Sea into the Barents Sea was higher than in 2004, and was also higher than the average for the observation period (1997-2005). However, the fluctuations through the year were the largest that are observed in this time series. In the beginning of the year the inflow were high, but dropped drastically in the spring, which is a crucial period for advection of zooplankton into the Barents Sea. The inflow then increased, and the inflow during the summer of 2005 is very high compared to the previous summers. This is a result of the already mentioned southeasterly winds during this period of time. Thereafter there was drop for a short time-period in late autumn 2005, before the inflow increased to record-high values in the winter of 2006. A wind driven model (Figure 4.14) is roughly in accordance with observations for the overlapping months.

The heat transport into the Barents Sea in 2005 was in general high. This is due to the combination of high temperatures upstream in the Norwegian Sea and above normal inflow conditions (Figure 4.13). However, though the temperature remained stationary high in the spring months the decrease in the inflow in the spring months resulted in a decreased heat transport in this period.

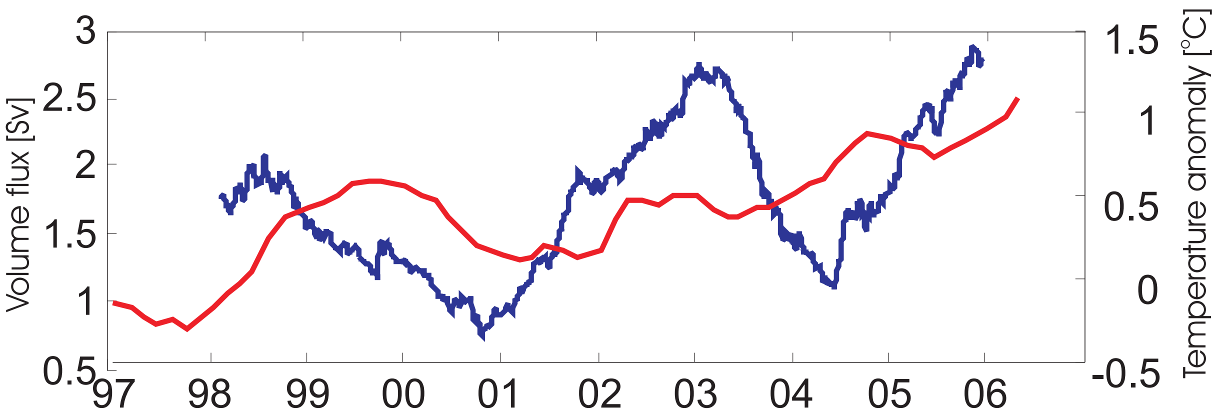


Figure 4.13. The blue lines shows the observed Atlantic Water volume flux through the section Norway-Bear Island estimated from current meter moorings. The red line shows observed temperature anomalies the section Fugløya – Bear Island section from CTD stations. Time series are 12 months running means.

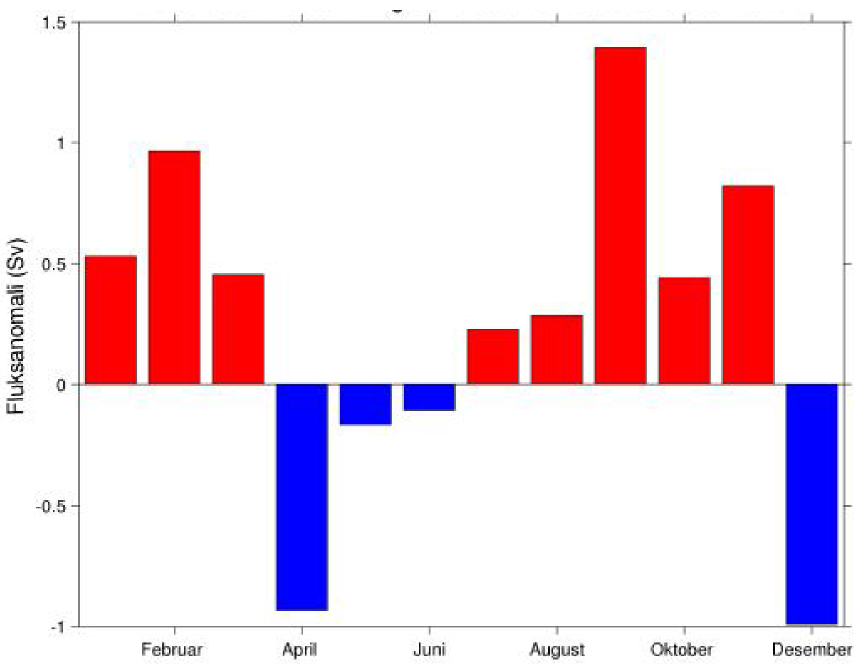


Figure 4.14. Modelled flux anomalies in 2005 through the section between Norway and Bear Island. The anomalies are deviations from the long-term mean period 1955-2005.

4.2.4 Ice conditions

In January the ice edge passed along 79°N, which is 200-400 miles further north than the long-term mean position. In February the total ice coverage of the sea was two times lower than the long term average and the least over the past 70 years. The total ice coverage was 12-20% less than the long-term mean for the rest of the year, and in August/September there was no ice in the Barents Sea (Figure 4.15 and Figure ***4.16***).

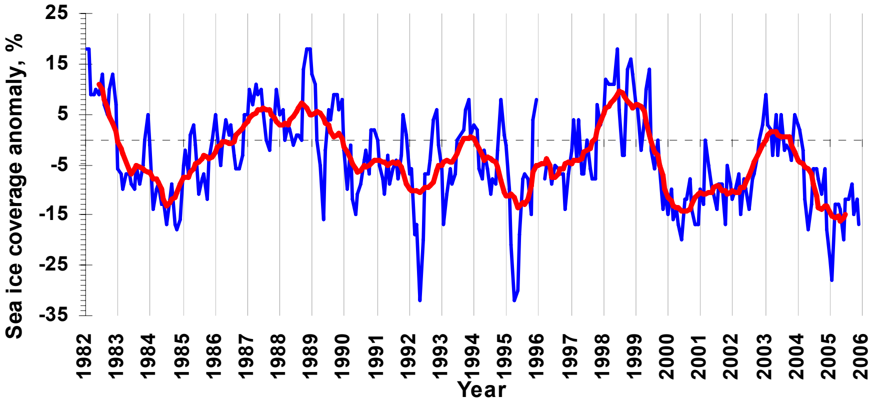


Figure 4.15. Ice coverage anomaly (% of the sea area) in the Barents Sea in 1982-2005 (Anon., 2006a).

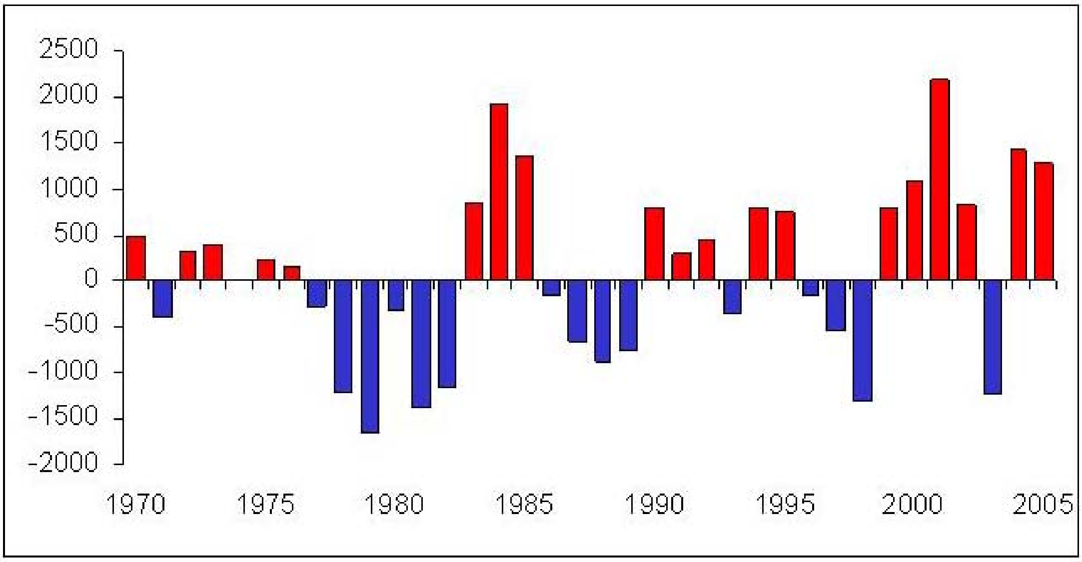


Figure 4.16. Ice index (IMR) for the period 1970-2004. Positive values means less ice than average, while negative values show more severe ice conditions.

4.2.5 Oxygen and phosphate conditions

The oxygen conditions in 2005 at the bottom in the southern Barents Sea were at an average level (Figure 4.17). This ended a long period of low oxygen content, which started in 1998. Anomalies of oxygen saturation in the bottom layer for the first 9 months of 2005 was 0.10 %, which were an increase from the similar period in 2004 (- 1.64 %).

Content of phosphates was close to the long-term mean level in 2005. Compared to the previous year the background content of mineral phosphorus decreased slightly. It was 0.07 µM lower than the long-term mean in the area of the Kola Section in the first half of 2005, whereas in 2004 the anomaly constituted minus 0.01 µM (See Figure 4.17) (Anon., 2006a).

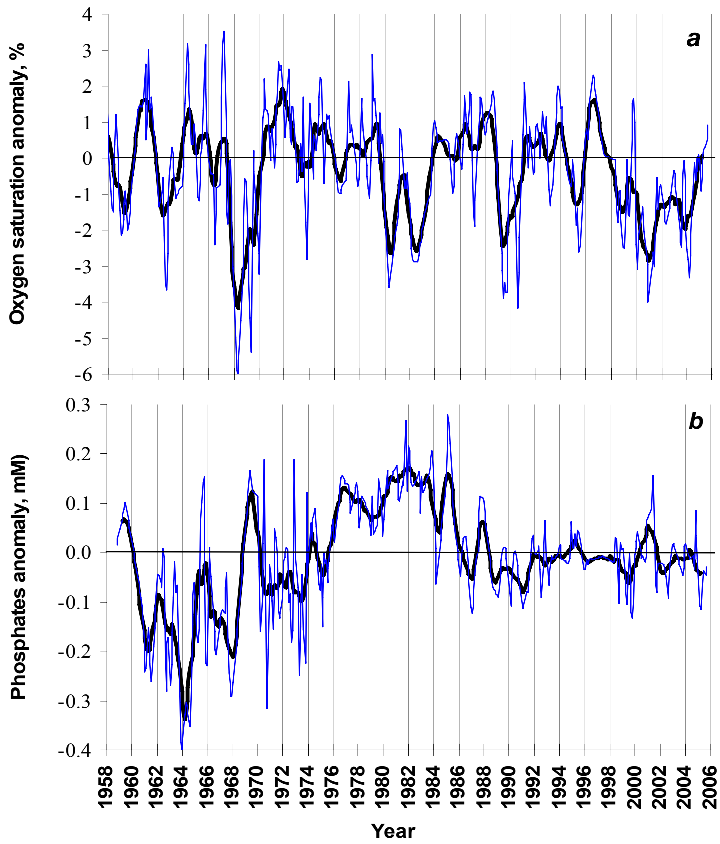


Figure 4.17. Anomalies of oxygen saturation (a, %) and phosphates concentrations (b, μM) in the bottom layer at stations 3-7 of the Kola Section for the period 1958-2004 (Anon., 2006a).

4.2.6 Expected situation

Temperature predictions

Prediction of forthcoming environmental conditions, or at least some knowledge on the predictability, is most valuable for projecting the survival of fish through the early life stages, as well as weight and maturity at age. The natural first environmental parameter to try to forecast is sea temperature. The rates of a number of growth-related processes are controlled by temperature (Michalsen *et al.*, 1998). In addition, temperature affects almost all species in the ecosystem, making it an important indicator of changes in fish population dynamics (Daan *et al.*, 1994). Furthermore, the "long memory" of the ocean, as compared to the atmosphere, makes it, at least a priori, feasible to realistically predict ocean temperature much further ahead than the typical weather forecast.

Prediction of Barents Sea temperature is complicated by the variation being governed by processes of both external and local origin operating on different time scales. The volume flux of Atlantic water masses flowing in from the Norwegian Sea is an important factor. It 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). Also the temperature of these water masses as well as local heat exchange with the atmosphere, possibly linked to atmospheric teleconnections, is important in determining the temperature of the Barents Sea (Ådlandsvik and Loeng, 1991; Loeng *et al*., 1992). Furthermore, also density differences in the ocean itself are of importance. 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 the literature suggests different time lags according to the distance to the upstream location. Helland-Hansen and Nansen (1909) suggested that a temperature signal takes 1 year from Fugløya-Bear Island to Kola, 2 years from Sognesjøen to Kola, while Sutton and Allen (1997) suggest that a SST signal takes 12-14 years from Cape Hatteras to NW Scotland. However, Ottersen *et al.*, (2000) didn't find much foundation for prediction based upon advection alone. Recently, Orvik and Skagseth (2003) studied the relation between the North Atlantic wind stress field and inflow to the Norwegian Sea. They found a maximum correlation of 0.88 between the volume transport of the Norwegian Atlantic Slope Current (NwASC) and the Zonally integrated North Atlantic Wind Stress Curl (NAWSC) at 55°N 15 months earlier. However, the calculations are based on data for the short period 1995-2003 and the correlative relation was not tested beyond the period it was derived for.

The major changes in Barents Sea climate take place during the winter months. The variability in the amount of heat flowing in with Atlantic water masses from the south is particularly high during this season. Furthermore, variability in low-pressure passages and cloud cover has an extra strong influence on the winter atmosphere-ocean heat exchange. The difference in temperature between ocean and atmosphere is highest, but highly variable, at this time of year. The air temperature may at times be 30 degrees lower than the SST. Thus, also with regards to the degree of loss of energy to the atmosphere, this season is decisive.

Ottersen *et al.,* (2000) showed that the seasonal difference can be reflected in the merit of simple six months forecasts of sea temperature based on linear regression models. They used data from the Kola section temperature time series (Bochkov, 1982), the longest below-surface sea temperature series in the region. The regression model showed that the predictive value for a specific month based on values from six months earlier vary considerably throughout the year. The tendency found was that of persistence across the spring and summer months being higher than for other seasons, allowing for reasonably reliable forecasts from spring until autumn.

Figure 4.18 shows a prognosis based on historical patterns in the time series (Anon., 2006a). Spectral analysis was used to identify dominant cycles (which accounted for about 80% of the inter-annual variation), and these cycles are further extrapolated into the future (Boitsov and Karsakov, 2005). According to this model the temperature in the southern Barents Sea is expected to decreases towards an average level in 2007. The temperatures is still expected be high in 2006.

An overall forecast of the temperature development for the Barents Sea must be based on subjective expertise, which takes into account statistical model results as well as the existing knowledge from adjacent areas. The temperature in the Barents Sea is expected to be high in 2006, especially in the first half. In the second half of 2006 the temperature is expected to decrease, but still be well above the long-term average. Though the inflow is largely depend on wind conditions, which is hard to predict, the above normal heat content of the Norwegian Sea, as well as above normal temperatures in the North Atlantic and North Sea, should ensure positive effect on the heat transport into the Barents Sea. For the Arctic water masses we do not have enough information to give a reliable forecast. The coastal water is expected to still be warm, due to the present high temperatures in the North Sea, but the uncertainty is quite high as the coastal waters also depends on the local atmospheric conditions.

It should be stressed that long-term predictions are fundamentally different from the global change scenarios for 50 or even 100 years ahead (e.g. ACIA, 2005). When modelling such scenarios a specific change in some important driving factor(s) is assumed (for instance a doubling of atmospheric CO_2 within a certain time span). The output is that of a future trend, not the situation for any specific year. Since the natural year-to-year variation still will be high, these kind of models will not be suited for determining if say 2050 will be a warm year or not. However, they can tell if the probability for higher temperatures in a given future year will change.

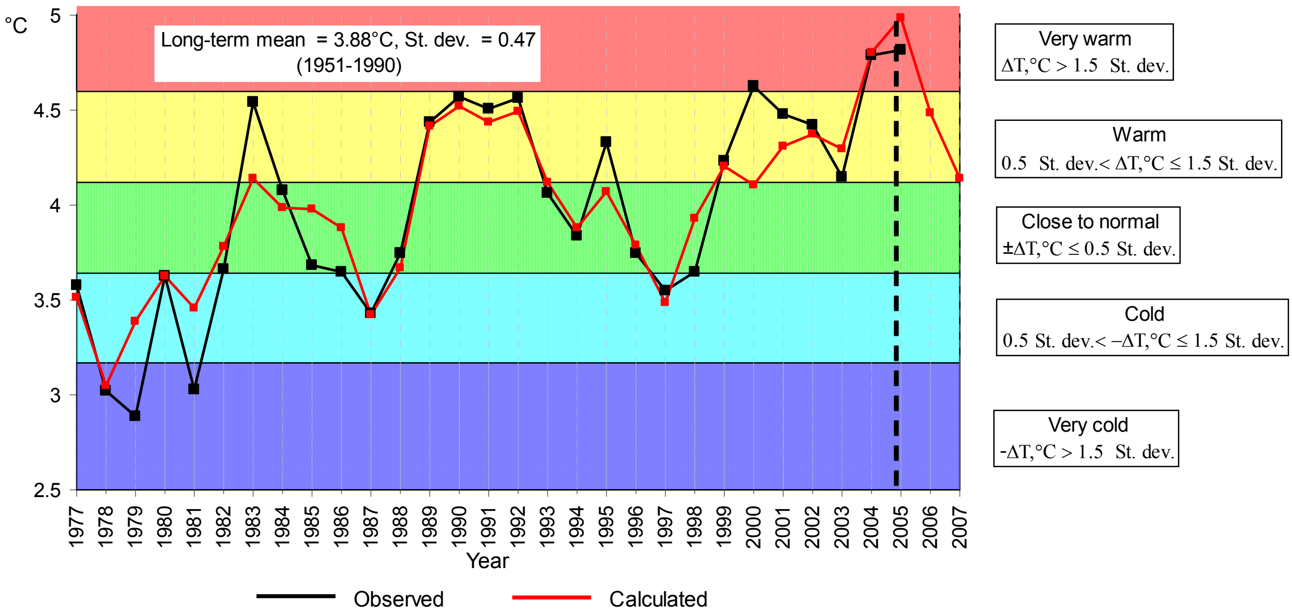


Figure 4.18. Observed and calculated temperature variations in the Kola Section (0-200 m) for the period 1977-2005, and temperature forecast up to 2007 (Boitsov and Karsakov, 2005).

Expected ice conditions

The ice conditions in the Barents Sea in 2006 is expected to still be low, due to the extremely warm Atlantic waters in the end of 2005 and beginning of 2006. However, at the end of the year it is expected to be somewhat more ice than in 2005, but still less than average, due to the expected decrease towards the average in the temperatures at the end of 2006.

4.3 Phytoplankton

4.3.1 Current situation

Figure 4.19 shows the measured chlorophyll values at the Fugløya-Bear Island section in March, April, June and August 2005. During the winter, the production is low and chlorophyll values are close to zero. In the period from January to March small flagellates dominated the phytoplankton.

In May variable concentrations of phytoplankton were measured on the Fugløya-Bear Island section. There was low diversity of species and the dominating group was diatoms. Relatively high concentrations of the diatom *Chatoceros decipience* were observed on the southernmost stations of the section.

On the Vardø-North section, high diversity of phytoplankton was observed in June, but concentrations were relatively low. Species of the *Chatoceros* genus dominated. In August the chlorophyll values was evenly distributed along the Fugløya-Bear Island section, with a tendency to higher production in the southern part. Small flagellates and big dinoflagellates were abundant along most of the section except for the southernmost stations were the big diatom *Proboscia alata* was frequently observed.

On the Vardø-North section in September, small flagellates dominated and *Emiliania huxlei* was most abundant. Measurements on the Fugløya-Bear Island section in October showed low concentrations of chlorophyll throughout the water column.

Simulations of the primary production in the Barents Sea using the ROMS numerical model (Skogen *et al*., in prep.) showed that there was considerable inter-annual variation in timing of the spring bloom at the Fugløya-Bear Island section during the years 1992 to 2005 (Figure 4.21). 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 show that the peak of the bloom may vary with about three weeks from year to year and in 2005 the results indicates that the bloom was relatively late. Figure 4.20 shows the timing of the bloom throughout the Barents Sea in 2005, which generally occurred 1-2 weeks later than in 2004. It shows that the bloom was earliest in the coastal waters close to the coast at the western entrance of the Barents Sea. Also along the Polar front and 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 Spitsbergen 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. The peak of the bloom in the Arctic water masses occurred 1-2 weeks later than in the Atlantic water masses, and at about the same time as in 2004. This indicates that the time difference in the peak of the blooms in the two water masses was less than in 2004.

4.3.2 Expected situation in 2006

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 depend 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.

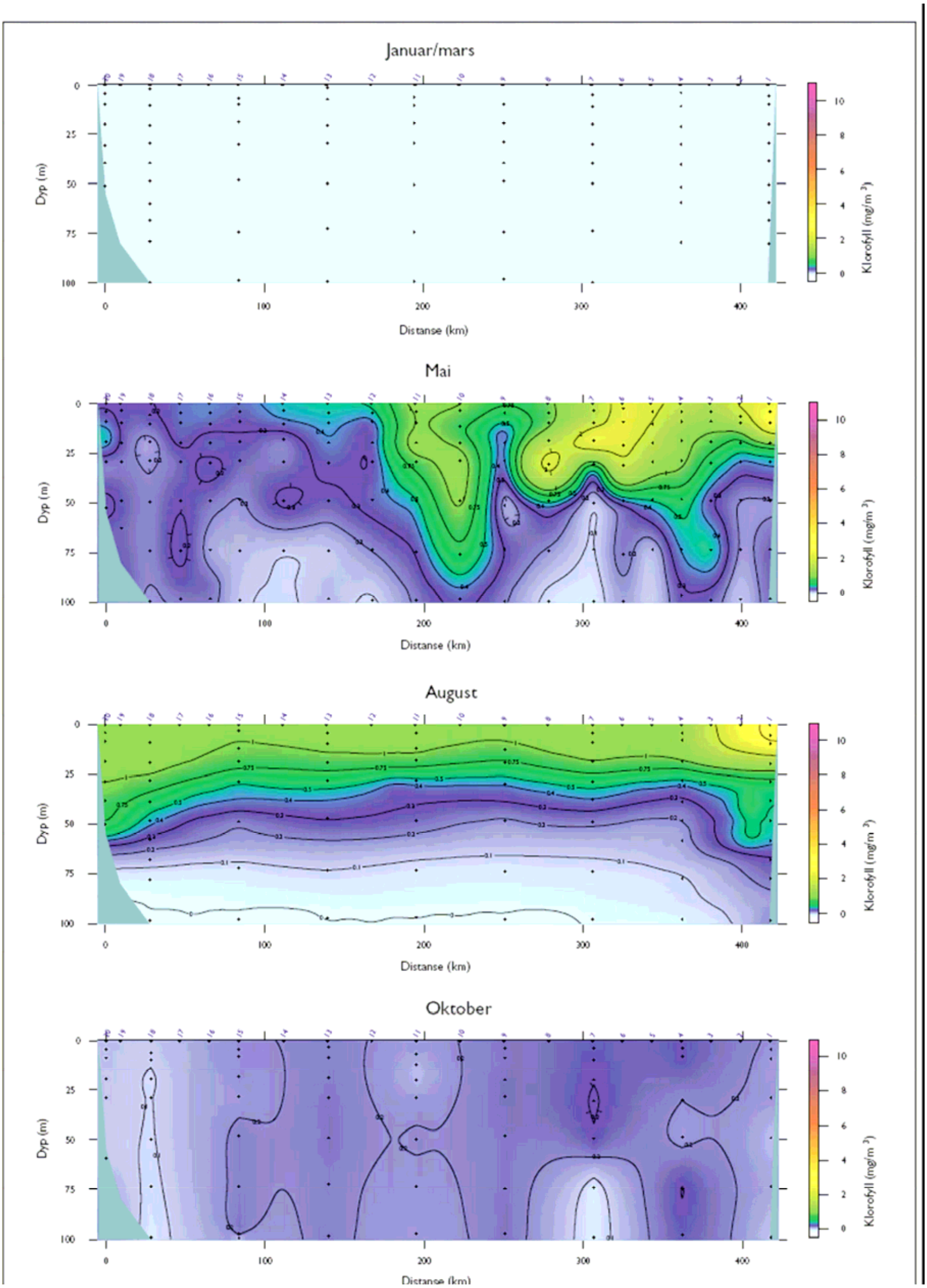


Figure 4.19. Measured chlorophyll in the upper 100 m on the transect Fugløya – Bear Island for 2005 in March, April, June and August. North to the left.

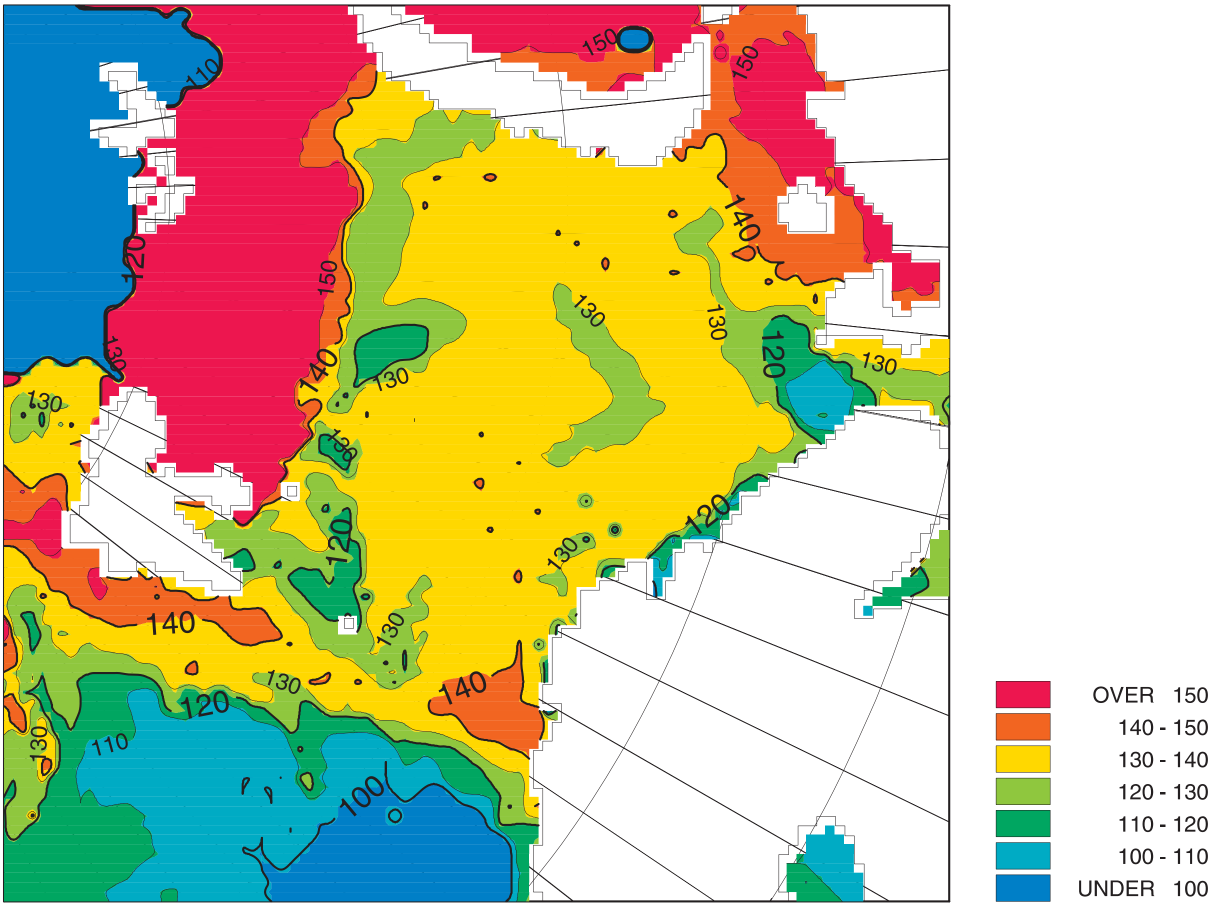


Figure 4.20. Modelled day number of peak diatom spring bloom in 2005 using the ROMS numerical model. Please note that in the dark blue area in the Arctic Ocean the day number of the peak is more than 150 (not under 100 as the colour bar indicated, which is correct for the rest of the map).

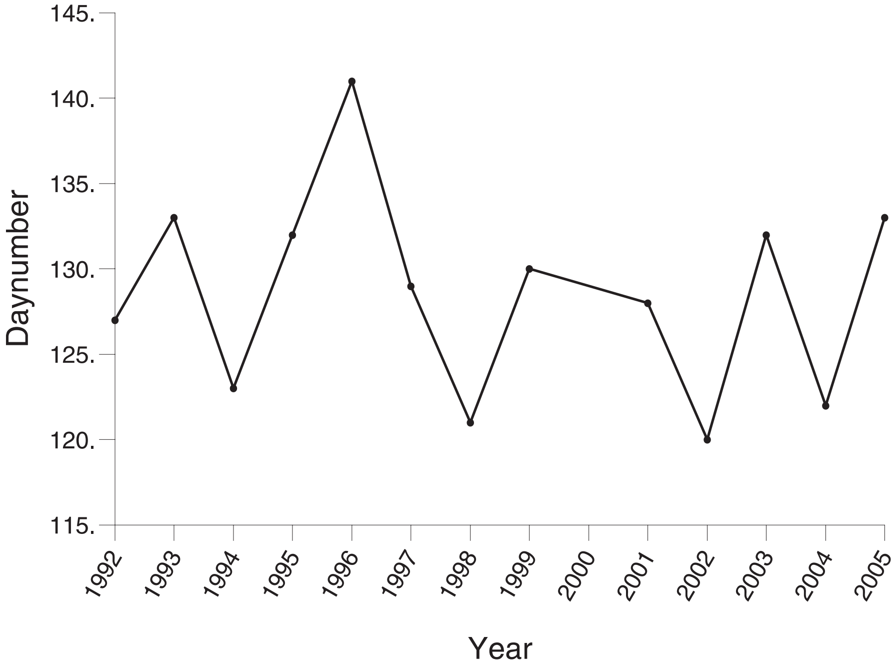


Figure 4.21. Modelled day number of peak diatom spring bloom at the Fugløya-Bear Island section during the period 1992 to 2005 using the ROMS numerical model.

4.4 Zooplankton

4.4.1 Autumn ecosystem survey

Results from the WP2 stations (Figure 4.22) show a mean biomass of 7.8 g m^{-2}, quite similar to 2004 values. When combining MOCNESS and WP2 zooplankton data average biomass was slightly higher in 2005 compared to 2004, 8.3 g m^{-2} and 8.0 g m^{-2} respectively. Although the average biomass was similar in both years, a low zooplankton biomass region in the south was observed in 2005 contrasting the situation in 2004. Predation, especially by 0+ herring (11 million tones) might explain the low plankton biomass found in the south. In general, the zooplankton biomass was higher in Atlantic/subarctic waters compared to Arctic waters (Table 4.2). *Calanus* and krill species contributed significantly to the high biomass of zooplankton observed in the western and central Barents Sea, while the high biomass localities observed in Arctic waters, was normally due to the presence of the large hyperid amphipod, *Themisto libellula*.

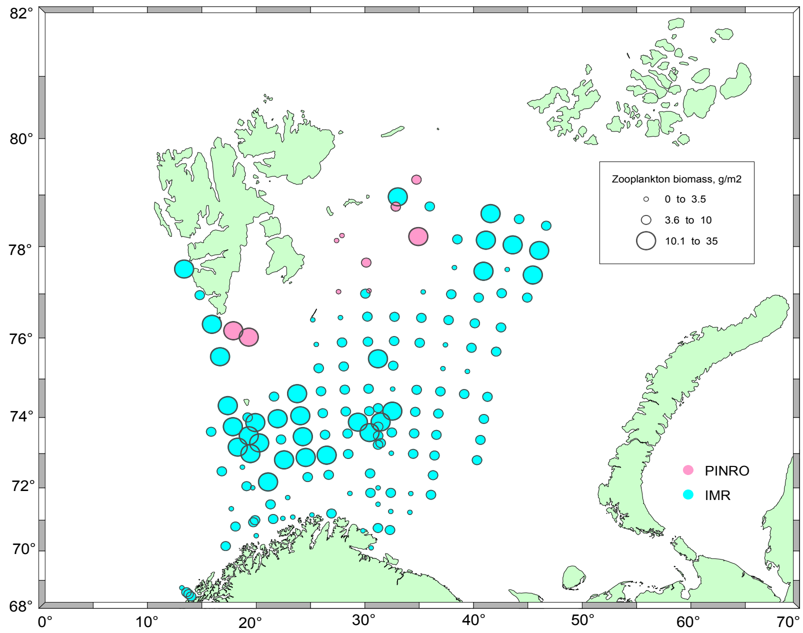


Figure 4.22. Horizontal distribution of zooplankton in 2005 (g m^{-2} of dry weight from bottom-0 m) based on WP2.

Table 4.2. Zooplankton dry weight (g m^{-2}) in different water mass categories in 2005.

Water Mass	No. stations	Average	SD
CW	9	3.69	2.67
CW-NAW	12	3.98	1.85
NAW	106	9.60	6.28
PFW	48	7.67	4.77
AW	16	8.53	5.70

Detailed analysis of distribution and age structure of *C. finmarchicus* and *C. glacialis* in 2004 revealed differences in their density and maturation in different areas. Highest biomass of *C. finmarchicus* was observed in the western and central Barents Sea in August with highest contribution from stages IV-V (approx. 800mg m^{-3}). *For C. glacialis* the biomass was highest in the northeastern parts of the Barents Sea with highest densities/biomass occurring in mid September. The biomass of *C. glacialis* (300-500 mg m^{-3}) in September was much higher than for C. finmarchicus (40-130 mg m^{-3}).

4.4.2 Fugløya-Bear Island transect

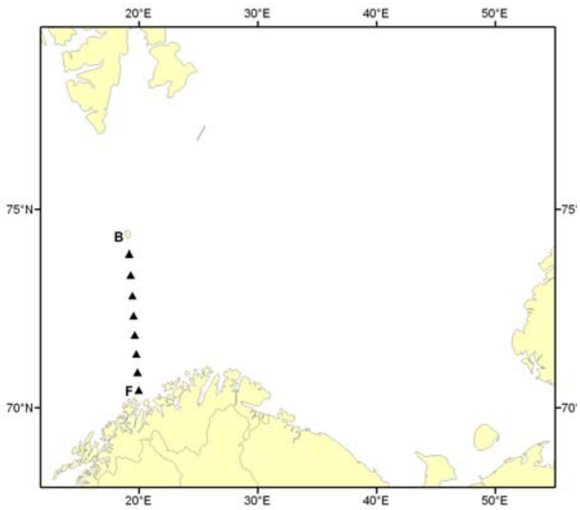


Figure 4.23. Zooplankton stations at Fugløya - Bear Island transect (FB) in 2005.

The mean zooplankton biomass along the FB section is very low during the winter months (Figure 4.24a,b). Very little zooplankton biomass (0.43g m^{-2}) was observed in the upper 100m during winter. A low biomass was also observed from bottom-0 m (1.7 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 =5.3 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 was 3.2 and 3.9 gm-2 in 2004 and 2005 respectively. This is below the long-term (1994-2005) average of 5.4 g m-2.

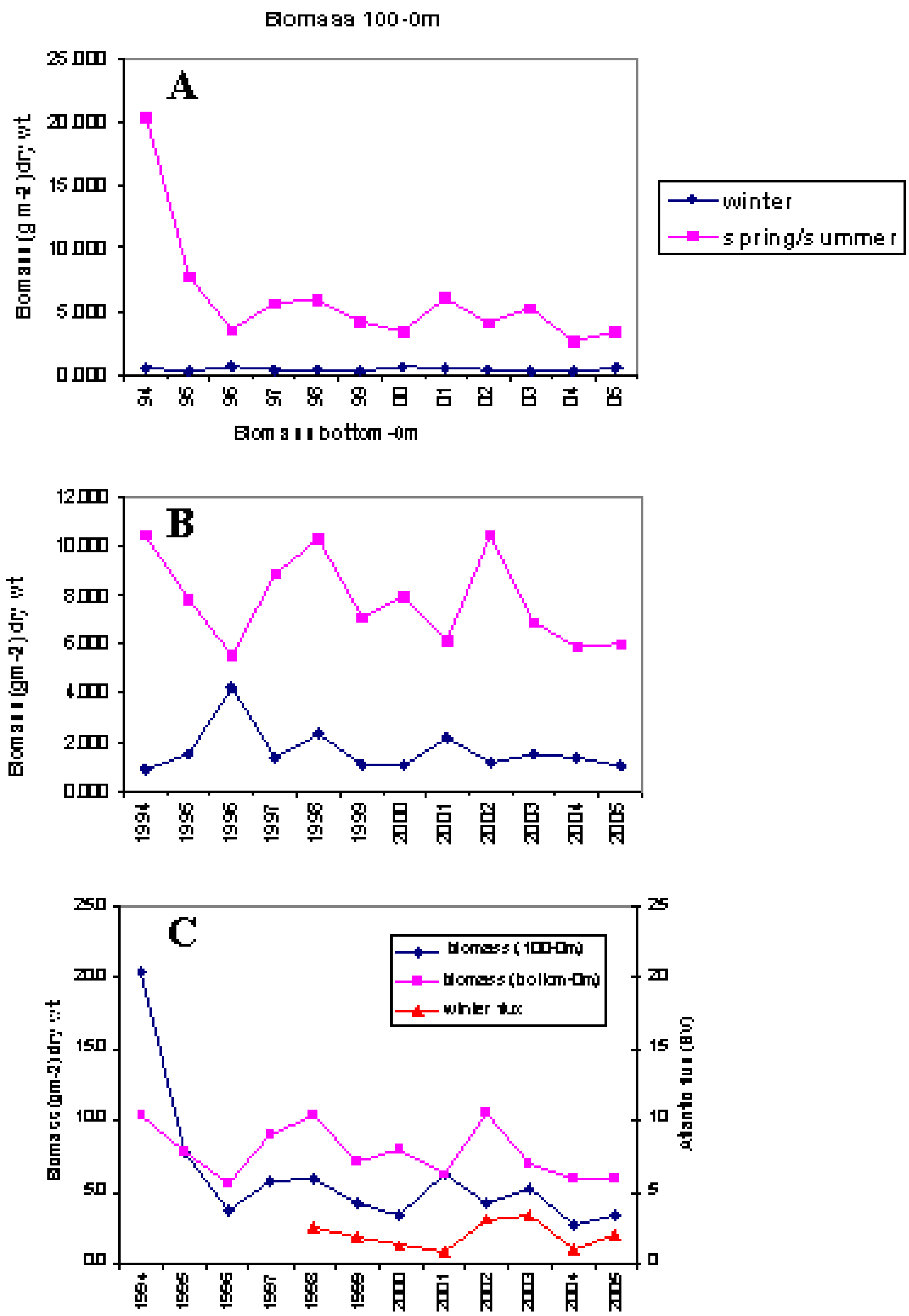


Figure 4.24. Mean annual zooplankton biomass (gm-2 dry weight) in the Fugløya-Bear Island transect a) 100-0m, and b) bottom-surface during winter (January-March) and spring/summer (May-August), c) Spring/summer biomass together in upper 100m with winter (January-March) Atlantic flux, from bottom-surface.

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 2005). The winter flow given in Figure 4.24c is from January 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 4.24c). 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 may play an important role in regulating the zooplankton biomass in the Barents Sea.

4.4.3 Autumn-winter macroplankton survey

Krill indices from northern and southern Barents Sea showed marked fluctuations (Figure 4.26). These indices of euphausiid abundance, expressed in ind./1 000 m^3, are calculated from euphausiids catches obtained by a net attached to a bottom trawl. The indices are derived as an arithmetic mean of all samples (Figure 4.25) taken within the various fishing areas corresponding to the scheme of the Barents Sea division, adopted by PINRO (Drobysheva *et al.,* 2003). Results show that the abundance of the pre-spawning krill in the beginning of 2005 was close to the long-term mean. The krill indices in the northern and southern regions during 2005 were slightly lower than in 2004. In 2005, the densest concentrations of krill (>5 000 ind./1 000 m^3) were registered northeast of the Hopen Island and in the southeastern shallows. Low concentrations of krill (1-100 ind./1 000 m^3) were observed in the coastal areas.

Although the krill abundance shows significant fluctuations, an increase in krill abundance can be seen from the early 1990's. Krill are mainly restricted to Atlantic/subarctic waters and penetrate very little into cold Arctic waters. The recent increase in krill abundance can be due to warmer conditions in the Barents Sea. This is supported by more frequent observations of the warm water krill species *Nematocelis megalops* in the Barents Sea in the recent years.

Another factor that may regulate the krill abundance is predation by fish, sea mammals and birds. Published information from the Barents Sea shows that krill are import food item not only for capelin, but also for cod (Bogstad and Mehl, 1997; Dalpadado and Bogstad, 2004). Krill constitute an important part of the diet of 0 group and age 1 cod. Older age groups of cod increase their consumption of euphausiids especially in years when capelin stock is at the low level.

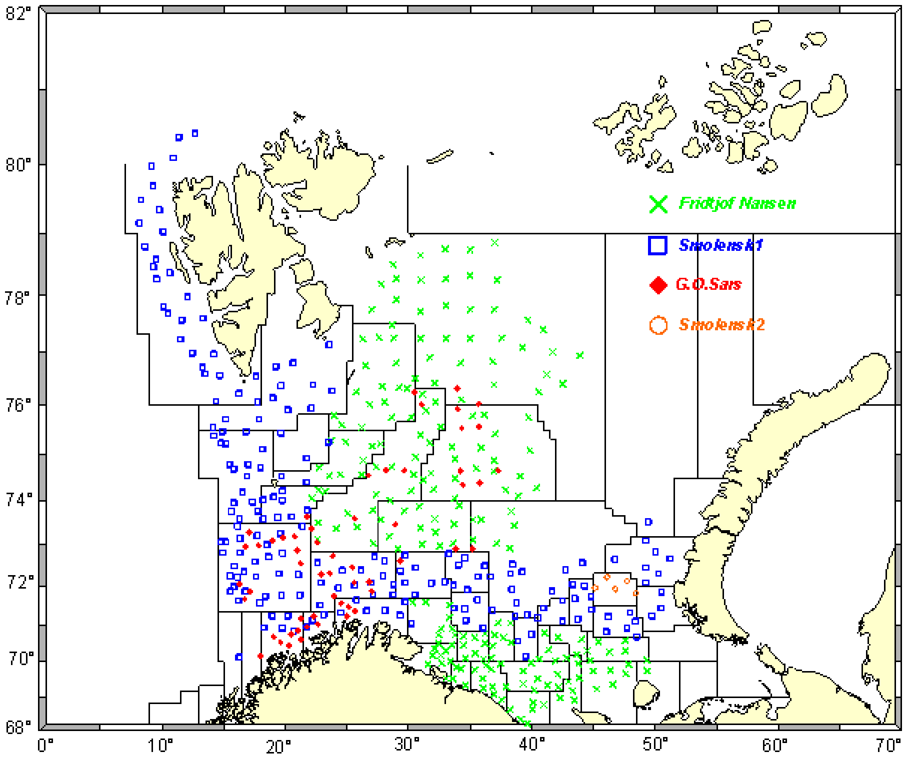


Figure 4.25. Map of the Barents Sea with the sampling stations where a net attached to the trawl was applied as a sampling gear during October-February 2004/2005.

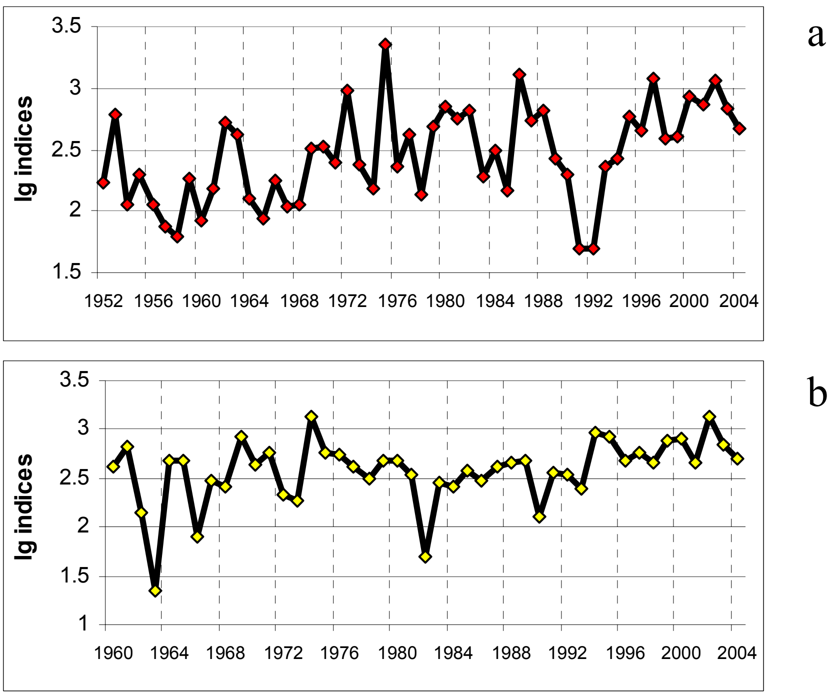


Figure 4.26. Indices of krill abundance in the southern (a) and in the northwestern part of the Barents Sea (b). More detailed area definitions can be found in Drobysheva et al. (2003)

4.4.4 Expected situation

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 show 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.

The average zooplankton biomass in 2005 from combined WP2 and MOCNESS data (8.3 g m^{-2}) was higher than long term mean (7.9 g m^{-2}). Abundance indices of the pre-spawning euphausiids in the beginning of 2005 were close to the long-term mean. Based on the biomass information we have from 2005 and the trend observed since 2001 the zooplankton production in 2006 is expected to be comparable to 2005, probably providing good feeding conditions for capelin, herring and other juvenile fish. However, a significant uncertainty exist with respect to the recovery of capelin, the developments of the blue whiting and herring stocks and how this might influence the growth in zooplankton stocks.

4.5 Fish

4.5.1 Cod

Based on the most recent estimates of spawning stock biomass (SSB), ICES classifies the stock as having full reproductive capacity. Based on the most recent estimates of fishing mortality, the stock is exploited with an unsustainable fishing mortality, much higher than that intended under the management plan. The SSB has been above Bpa since 2002. Fishing mortality was reduced significantly over the years 1999-2003 but has since then increased to a 2005 estimate equal to Flim. Surveys indicate that recent year classes are at or below average.

The current fishing mortality (F), estimated at 0.74, is above fishing mortalities 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 2005 indicate about 35% 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.

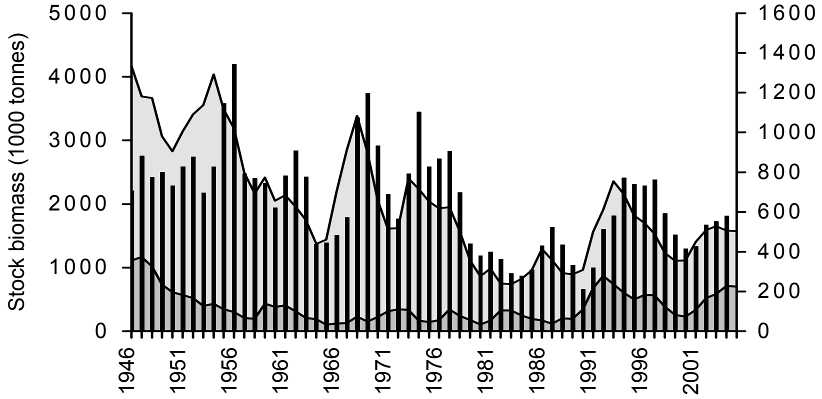


Figure 4.27. Northeast Arctic cod, development of spawning stock biomass (dark area) total stock biomass (age 3 and older, total area) and landings (columns).

4.5.2 Haddock

Based on the most recent estimates of SSB, ICES classifies the stock as having full reproductive capacity. The assessment is uncertain due to a major revision of data and substantial unreporting of landings, but believed to be indicative for trends. Recent recruitment has been average with no large year classes.

There are indications that the current fishing mortality is above fishing mortalities that would lead to high long-term yields. 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.

The dynamics of this stock have in the past been driven by sporadic strong year classes that lead to wide fluctuations in the SSB. In recent years, recruitment has been more stable; this could be attributed to the good state of the spawning stock biomass and favourable high water temperature conditions. At the same time the reduced level of the capelin stock in the Barents Sea leads to increased predation by cod.

Haddock is taken both as a directed fishery and as bycatch in the NEA cod fishery.
Also for haddock there are concerns about under-reporting of catches in recent years. Unreported landings will reduce the effect of management measures and will undermine the

intended objectives of the harvest control rule. It is important that management agencies ensure that all catches are counted against the TAC.

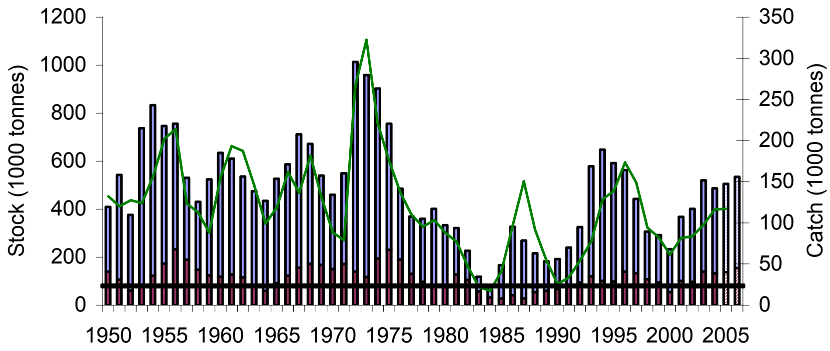


Figure 4.28. Northeast Arctic Haddock, development of total stock biomass (age 3 and older, whole columns), spawning stock biomass (dark part of columns) and catches (solid line) in the period 1950 to 2006. The years 2005 and 2006 are based on prognoses. The horizontal line represents the precautionary level of spawning stock biomass (Bpa).

4.5.3 Redfish

Deep-Sea Redfish

In the absence of defined reference points the state of the deep-sea redfish stock cannot be fully evaluated. The only year classes that can contribute to the spawning stock are those prior to 1991 as the following 15 year classes are extremely poor. Surveys indicate that the stock, at present, is near a historical low. The 1991-2005 year classes are indicated to be well below those of the 1980s.

Recruitment failure has been observed in surveys for more than a decade. 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 Spitsbergen area. This will ensure that the recruiting year classes can contribute as much as possible to stock rebuilding.

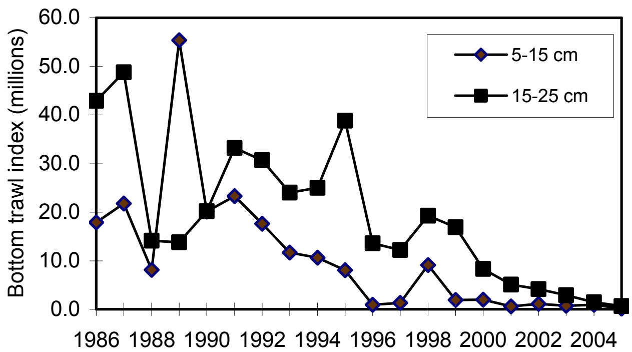
The only year classes that can contribute to the spawning stock are those prior to 1991 as the following year classes are extremely poor. Consequently, these year classes need to be protected as they offer the only opportunity of increasing the spawning stock for a number of years to come. This should include the pelagic fisheries in the Norwegian Sea.

Based on estimates of current SSB and the size of year classes in the 1990s, 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.

Golden Redfish

In the absence of defined reference points the state of the stock cannot be fully evaluated. Surveys 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 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.



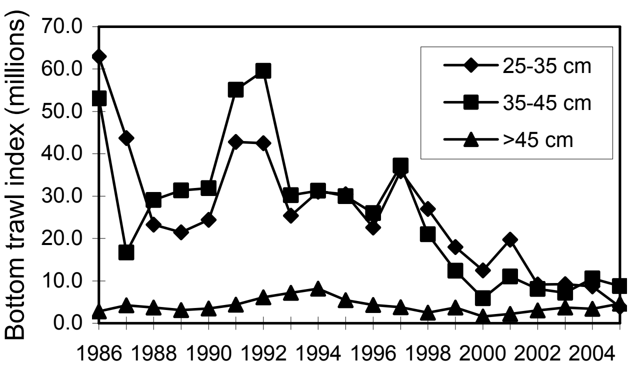


Figure 4.29. Sebastes marinus. Abundance indices (by length) when combining the Norwegian bottom trawl surveys 1986-2005 in the Barents Sea (winter) and at Spitsbergen (summer/fall).

4.5.4 Greenland halibut

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. 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.

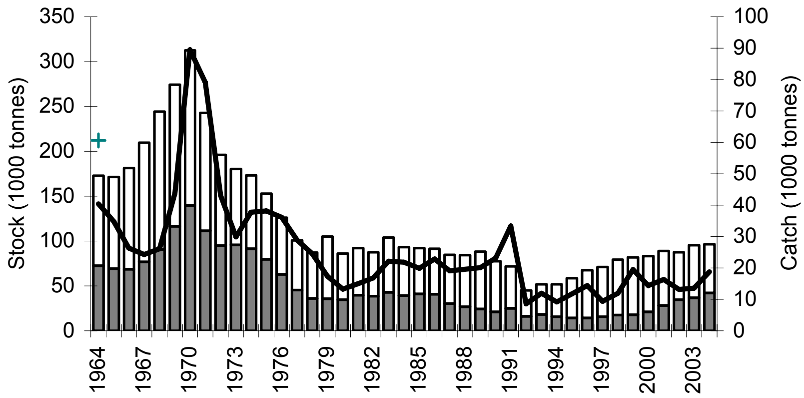


Figure 4.30. Northeast Arctic Greenland halibut; development in total stock biomass (age 5 and older, open columns), spawning stock based on mature females (solid columns) and landings (solid line) 1964-2004.

4.5.5 Capelin

The spawning stock of capelin in 2006 is predicted from the acoustic survey in September 2005 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 2006, the probability of having an SSB below 200,000 t is above 95%. 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 2005 was estimated to be 0.17 mill tonnes. SSB 1st April 2006 is predicted to be at 0.072 mill tonnes, which is far below Blim. The spawning stock in 2006 will consist of fish from the 2002 and 2003 year classes, but the 2003 year class will dominate. The survey estimate at age 1 of the 2004 year class is far below the long-term average. Observations during the international 0-group survey in August-September 2005 indicated that the size of the 2005 year class is somewhat below 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 1984-2004. 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. The abundance of herring in the Barents Sea is believed to stay at a high level in 2006.

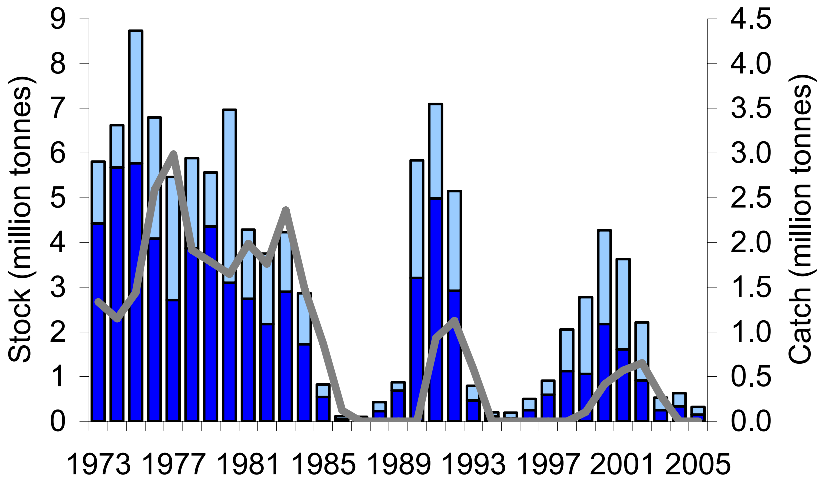


Figure 4.31. Barents Sea capelin. Total stock (bars) and maturing component (light part of bars) during autumn, and total landings (curve), 1973–2005.

4.5.6 Herring

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 at around 6.3 million t in 2005. The 2002 year class is estimated to be strong and will recruit to the fishery in 2006 and 2007. Preliminary indications show that the 2004 year class may also be strong.

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

Juveniles and adults of this stock form an important part of the ecosystems in the Barents Sea, the Norwegian Sea, and the Norwegian coast. The herring has an important role as transformer of the plankton production to higher trophic levels (cod, seabirds, and marine mammals). Recent changes in the herring migration have led to increased proportion feeding in Faeroese and Icelandic waters in the southwestern Norwegian Sea. The growth of these herring is faster than those feeding further east and north. A relationship between climate and herring growth is used to predict weights for the short-term forecast.

4.5.7 Polar cod

The polar cod stock is presently at a high level. 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 2005, the stock size was measured to about 1.8 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 for different stocks of seals and cod.

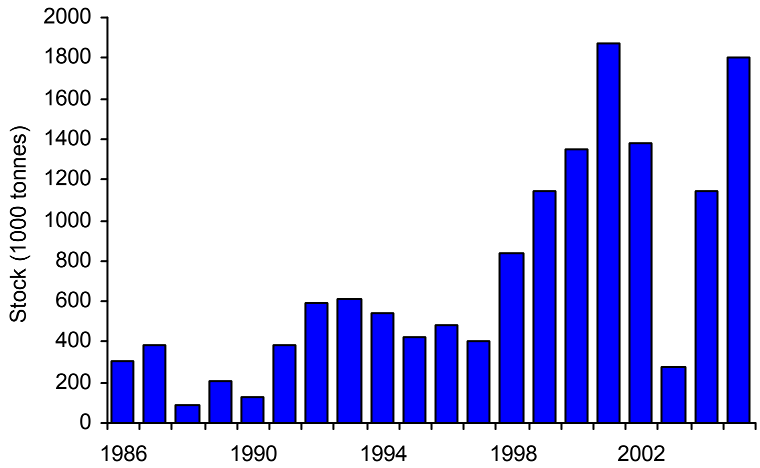


Figure 4.32. Polar cod. Stock size estimates obtained by acoustics, 1986–2005.

4.5.8 Blue whiting

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 and 2005. Although the estimates of SSB and fishing mortality are uncertain, the estimate of SSB appears to be well above Bpa. The estimated fishing mortality is well above Fpa, and is estimated to have exceeded Flim in 2004. Recruitment in the last decade appears to be at a much higher level than earlier, and the good recruitment appears to have continued in 2004.

Total landings in 2004 were 2.4 mill. tonnes, almost the same as in 2003. Recent large landings are supported by the current high recruitments, and are much higher than in earlier years. Most of the catches are taken in the spawning- and post spawning areas along the continental edge, and in the Norwegian Sea. In the latter, the share of the total catch has increased from 5% in the mid nineties to about 40% in 2003 and 2004. A larger proportion of the catch there consists of young fish. As a result, the age structure in the stock has changed considerably, and the stock now largely lacks fish older than 6 years.

The increased abundance of blue whiting in the Barents Sea 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 2004-2005. In autumn 2005, the acoustic abundance of blue whiting was estimated to 1.1 million tonnes, mainly age 1-5 fish.

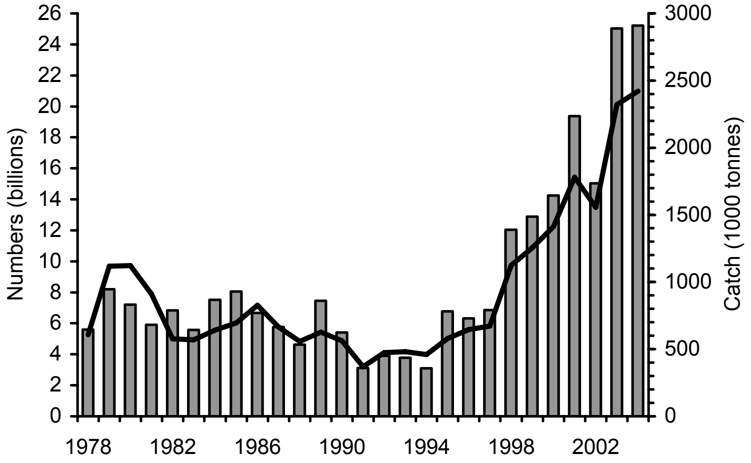


Figure 4.33. Blue Whiting. Catch in numbers (bars) and tonnes (line), 1978 – 2004.

4.5.9 Recruitment

Table 4.3 presents area based 0-group indices for the most important demersal and pelagic species in the Barents Sea 1965-2005. In addition stratified mean indices, with and without correction for catching efficiency, are estimated for the period 1980-2005. The abundance of 0-group cod was slightly above average level in the two last years, while it was well above average in the period 1992-1995. For haddock the three last indices are the highest in the time series, while in earlier years there were normally several years between strong year classes. Redfish had indices at or above average level until 1990, when the recruitment suddenly dropped and continued to decrease to historical low levels. The abundance in 2005 was higher than in the last ten years but below the long-term mean. The 0-group abundance of Greenland halibut fell below average level in 1988 and stayed at a low level until 1999, after which most of the indices have been above average level, except for 2003 and 2005. The indices for long rough dab show considerable variations, but no clear trends. Of the pelagic species, capelin had indices at or below average level in the two last years, while the best period was in the beginning of the 1980s. After a long period of very low abundance, the herring stock started to rebuild with the 1983-year class. Of later year classes, those from 1996-1998, 2000 and 2004 have been strong or well above average. The polar cod is separated in a western and eastern component. Both sets of 0-group indices show large variations, but do not follow the same pattern. There seems to have been an increase in the indices of the eastern component after 1990.

Recruitment seems to be strong for most fish species, so that, in addition to young herring, also haddock, blue whiting, polar cod and cod are abundant in the Barents Sea. It is thus likely that cod and other predators, except capelin specialists like the seabird guillemot, will have alternative fish prey available, as in the mid-1990s. It is thus most likely that the consequences of this capelin collapse will be modest and fairly similar to those in the mid-1990s. Another interesting phenomenon is that the collapse of the capelin stock is less abrupt this time than in the two previous collapses, because the recruitment failure has not been so drastic. We also note that recruitment of 0-group capelin has not failed in 2002-2005, while the survival from 0-group to age 1 seems to be poor. Whether this is due to predation by herring on 0-group capelin after the survey on 0-group capelin in August-September, is unknown.

Table 4.3. Abundance indices (area method) of 0-group fish in the Barents Sea and adjacent waters in 1965-2005.

Year	Capelin[1]	Cod[2]	Haddock[2]	Herring[3]	Polar cod		Redfish	Greenland halibut	Long rough dab
					West	East			
1965	37	11	13	-	0		159	-	66
1966	119	2	2	-	129		236	-	97
1967	89	62	76	-	165		44	-	73
1968	99	45	14	-	60		21	-	17
1969	109	211	186	-	208		295	-	26
1970	51	1097	208	-	197		247	1	12
1971	151	356	166	-	181		172	1	81
1972	275	225	74	-	140		177	8	65
1973	125	1101	87	-	26		385	3	67
1974	359	82	237	-	227		468	13	93
1975	320	453	224	-	75		315	21	113
1976	281	57	148	-	131		447	16	96
1977	194	279	187	-	157	70	472	9	72
1978	40	192	110	-	107	144	460	35	76
1979	660	129	95	-	23	302	980	22	69
1980	502	61	68	-	79	247	651	12	108
1981	570	65	30	-	149	93	861	38	95
1982	393	136	107	-	14	50	694	17	150
1983	589	459	219	-	48	39	851	16	80
1984	320	559	293	-	115	16	732	40	70
1985	110	742	156	-	60	334	795	36	86
1986	125	434	160	-	111	366	702	55	755
1987	55	102	72	-	17	155	631	41	174
1988	187	133	86	-	144	120	949	8	72
1989	1330	202	112	-	206	41	698	5	92
1990	324	465	227	-	144	48	670	2	35
1991	241	766	472	-	90	239	200	1	28
1992	26	1159	313	-	195	118	150	3	32
1993	43	910	240	188	171	156	162	11	55
1994	58	899	282	120	50	448	414	20	272
1995	43	1069	148	73	6	0	220	15	66
1996	291	1142	196	378	59	484	19	5	10
1997	522	1077	150	390	129	453	50	13	42
1998	428	576	593	524	144	457	78	11	28
1999	722	194	184	242	116	696	27	13	66
2000	303	870	417	213	76	387	195	28	81
2001	221	212	394	77	110	146	11	32	86
2002	327	1055	412	315	179	588	28	34	173
2003	630	694	705	277	164	337	57	9	58
2004	288	983	977	639	62	355	98	29	35
2005	348	972	1103	205	154	273	247	8	89
1985-2005	315	698	352		114	266	305	18	111
1965-2005	290	494	243				368	18	94

[1] Assessment for 1979-1993 in Ushakov and Shamray (1995)

[2] Indices for 1965-1985 for cod and haddock adjusted according to Nakken and Raknes (1996)

[3] Calculated by Prozorkevich (2001)

4.6 Marine mammals

4.6.1 Current situation

Abundance and distribution of some marine mammal species in the Barents Sea are regularly monitored. With the exception of polar bears (3000 individuals, Norwegian Polar Institute 2005), no abundance estimates are available for the ice-associated marine mammals. Hence, there is little information available to evaluate year-to-year variation in abundance of marine mammals in the Barents Sea in relation to annual fluctuations in the Barents Sea ecosystem. Nevertheless, being long-lived animals with long generation times, annual fluctuations in the system are more likely to be reflected in the distribution of the marine mammals rather than the abundance.

In summer/autumn surveys the minke whale was the most frequently seen species of the large cetaceans (Table 4.4), but fin whales were also quite common, even within the Barents Sea proper. The dolphin-like species observed were dominated by whitebeaked dolphins (Lagenorhynchus albirostris). A significant number of sperm whales were seen off the continental shelf of northern Norway south of about 72ºN.

The minke whales were distributed all over the area surveyed, while fin whales were mostly seen north of about 74ºN within the Barents Sea, along the continental shelf break and offshore within the Norwegian Sea (Figure 4.34 and Figure ***4.35***). Humpback whales were seen south of Bear Island and in an area northeast of Hopen Island (Figure 4.35), both traditional feeding grounds for humpbacks at this time of the year. Dolphins were observed all over the survey area with exception of the deepest areas in the Norwegian Sea (Figure 4.35).

In 2005, migrations of cetaceans in the Barents Sea appeared to be more prolonged both in time of presence in the sea and distance (Figure 4.36 and Figure ***4.37***). An increase was observed in occurrence of rare species for this area (northern bottlenose whale, pilot whale, sei whale, fin whale, sperm whale). Concentrations of sea mammals (humpback whales and dolphins) at sites of high potential food aggregations were more dense and prolonged than in 2003 and 2004. From 2004 to 2005 some changes in distribution of marine mammals were evident; for example were fin and humpback whales in 2005 mainly observed in the northern part of the sampling area in association with capelin and polar cod.

In the Barents Sea, minke whales were distributed practically in the entire area and observed to form considerable aggregations off the Murman coast. The large group of minke whales in the southeastern Barents Sea was connected with the approaches of both capelin and Cheshsko-Pechorskaya herring to that area. The concentration was stable during the whole summer (Figure 4.36 andFigure ***4.37***).

The occurrence of northern bottlenose whales Hyperoodon ampullatus to the Barents Sea area (primarily to the western part) has become more frequent (Figure 4.38). The whales were observed in the area of the Kopytov Bank and off the western slope of the Bear Island Bank, over depths from 200-700 m to 1500 m. Mean water temperature in the areas of their occurrence was +4º - +6ºC. To the east of 20ºE and to the north of 76ºN, no bottlenose whales were recorded. The animals were registered as single specimens or in groups of 2-5 to 8-11 individuals. In the groups both adult and young whales as well as calves were recorded. The total abundance of the observed group of bottlenose whales was estimated at 190-200 individuals. This species may have an influence on long-line fishing since some groups of bottlenose whales feed on fish caught by longlines.

In March 2005 an airborne estimation of pups of harp seals was conducted in the White Sea. The estimated abundance of harp seal pups, 122400 (SE=19,900), was less than those estimated in recent years. The total abundance of seals having been registered in the moulting grounds in April 2005 was estimated by an automatized method using the thermal scanner images and control comparison with the data obtained in the traditional way (based on the joint procession of IR-images and digital video). According to the data from the assessment in the seal moulting grounds in the White Sea, the total abundance amounted to 654050 individuals (SE=174,200). The data obtained indicate a decrease in harp seal abundance at the reproduction and moulting grounds in spring 2005. However, the reasons for this are unknown.

During the aerial surveys in March-April in the White Sea ice area, a group of white whales was observed scattered in the open water along the dense ice edge, and their abundance was estimated to be 1,000-1,500 individuals. In March, the group was located in the White Sea Basin; in April, a second group was formed in Voronka. In April, in the Voronka of the White Sea, a group of walruses (23 animals recorded), the largest one observed in recent years, was found (Figure 4.39).

From 2003 to 2004 some changes in distribution of marine mammals were evident. In 2003 the fin, humpback and minke whales were mainly observed in the northern part of the sampling area, in association with capelin and polar cod. In 2004 these species were also observed in the southern part of the sampling area, thus overlapping with capelin and polar cod in the north and herring and blue whiting in the south. Both herring and capelin were more abundant in 2003 than in 2004, while polar cod was more abundant in 2004 than in 2003. Hence, there are no obvious reasons for the southward displacement of the baleen whales.

A character of the revealed distribution of marine mammals in summer/autumn in the Barents Sea is probably a consequence of the influence of both warming (earlier spring migration) and decrease of food base (capelin). However, at present time the spatial associations between the marine mammal species and potential prey species have not yet been properly quantified and assessed. Also, effects of varying observer effort and weather conditions needs to be taken into account before any conclusions can be drawn as some baleen whale species are difficult to observe under windy conditions, and weather conditions may thus severely influence the observed distributions.

Table 4.4. Observations of marine mammals during the 2005 surveys.

Species	Number of observations	Number of animals
Minke whale	147	158
Fin whale	76	137
Humpback whale	22	34
Sperm whale	70	77
Bottlenose whale	6	13
Killer whale	14	54
Whitebeaked dolphin	122	686
Unidentified dolphin	53	252
Harbour porpoise	2	4
Large whale	29	43
Unidentified whale	3	3
Unidentified seal	1	1

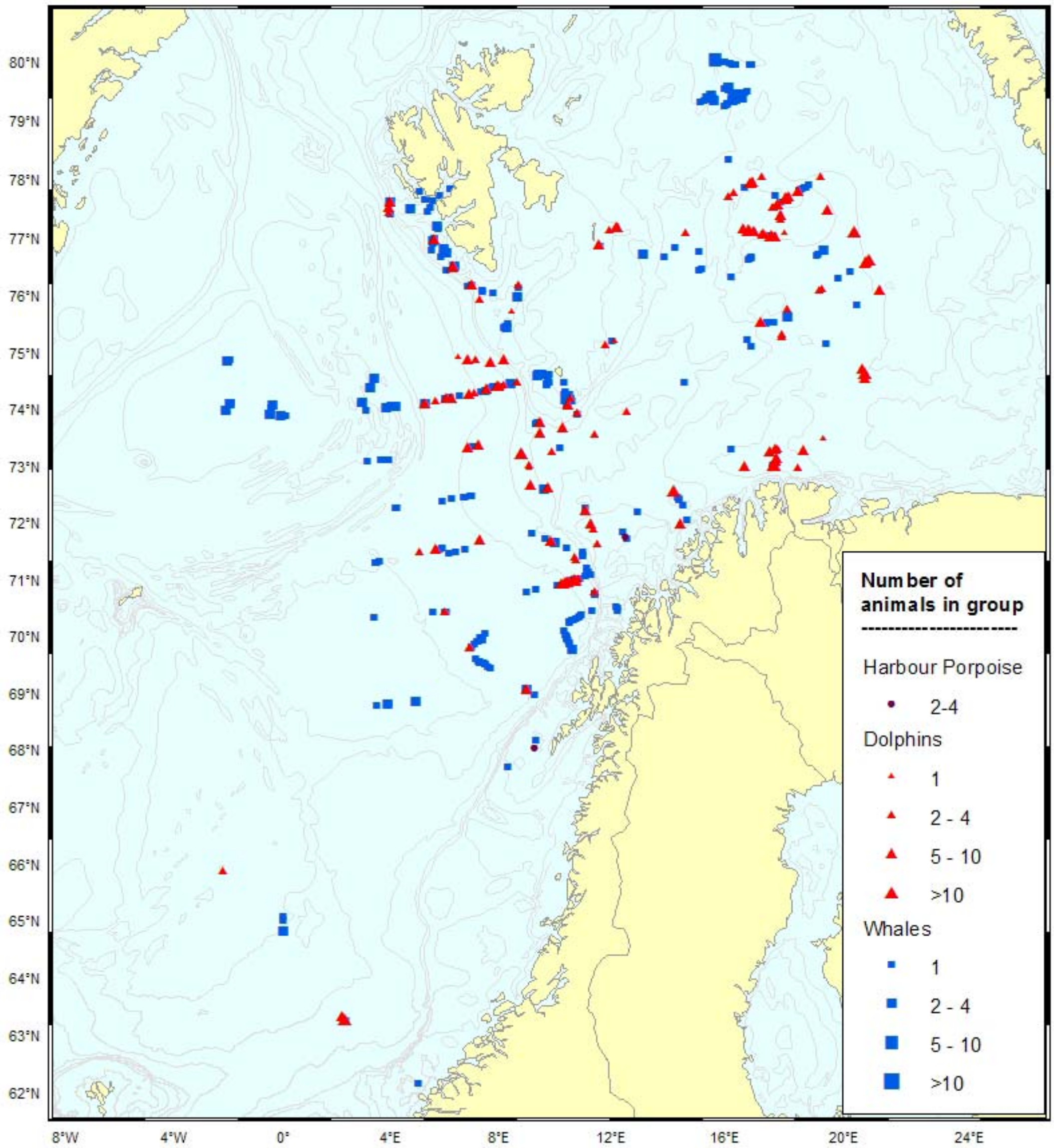


Figure 4.34. Distribution of observations of marine mammals.

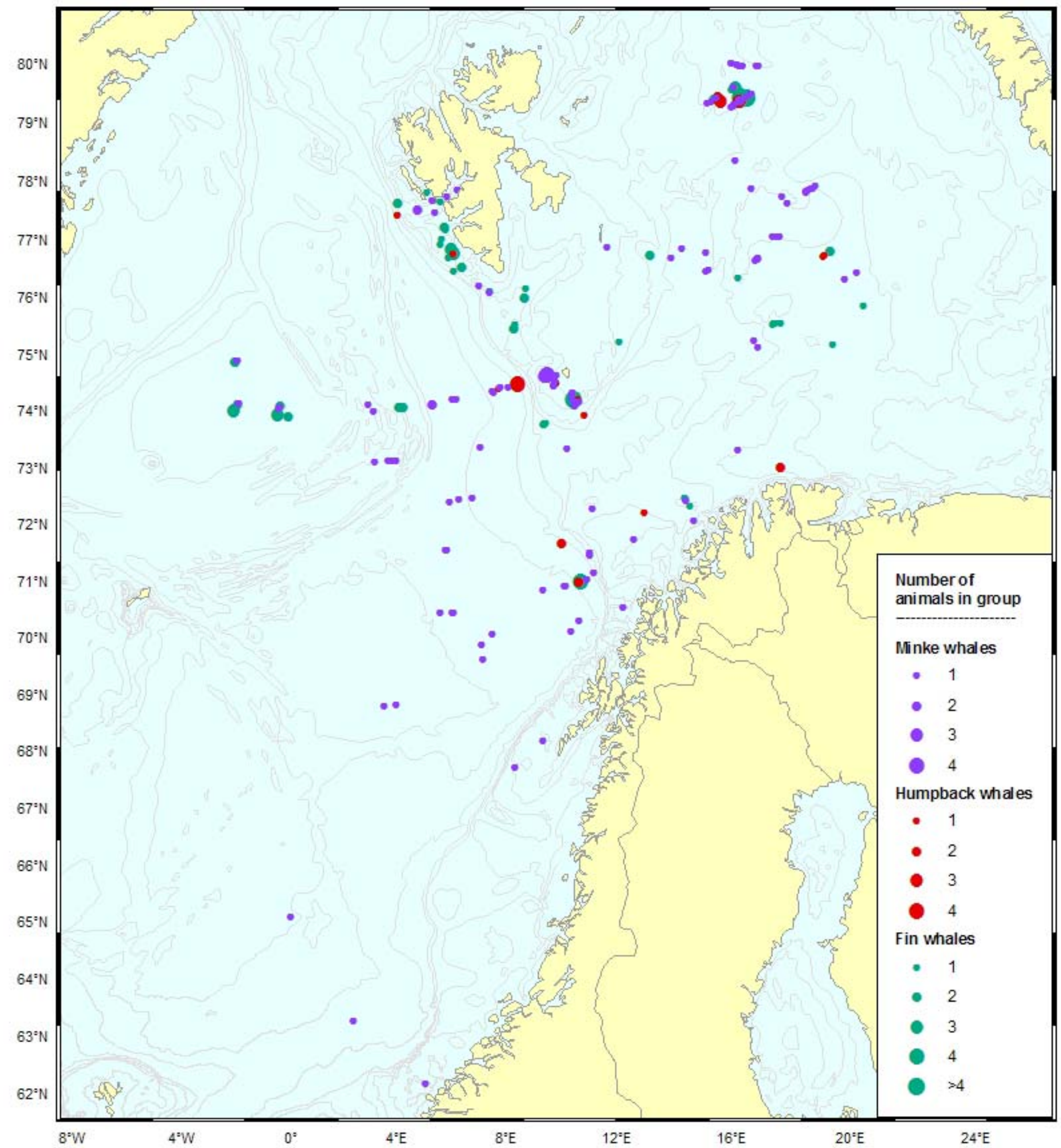


Figure 4.35. Observation of the main species minke whales, humpback whales and fin whales during the 2005 surveys.

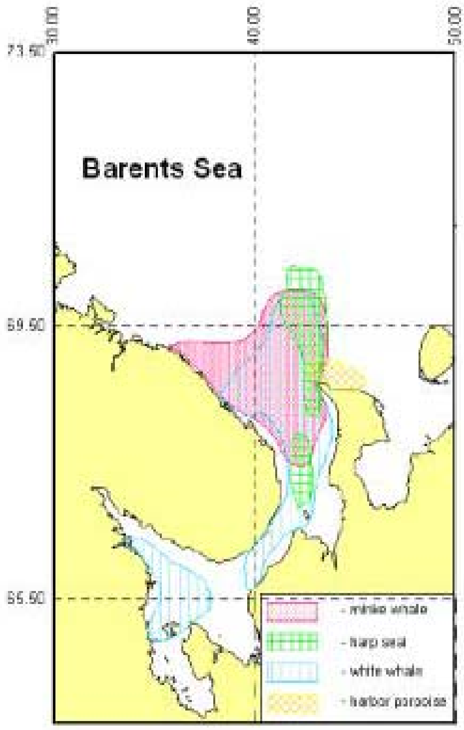


Figure 4.36. Summer aggregations of marine mammals in the souteastern Barents Sea in July 2005.

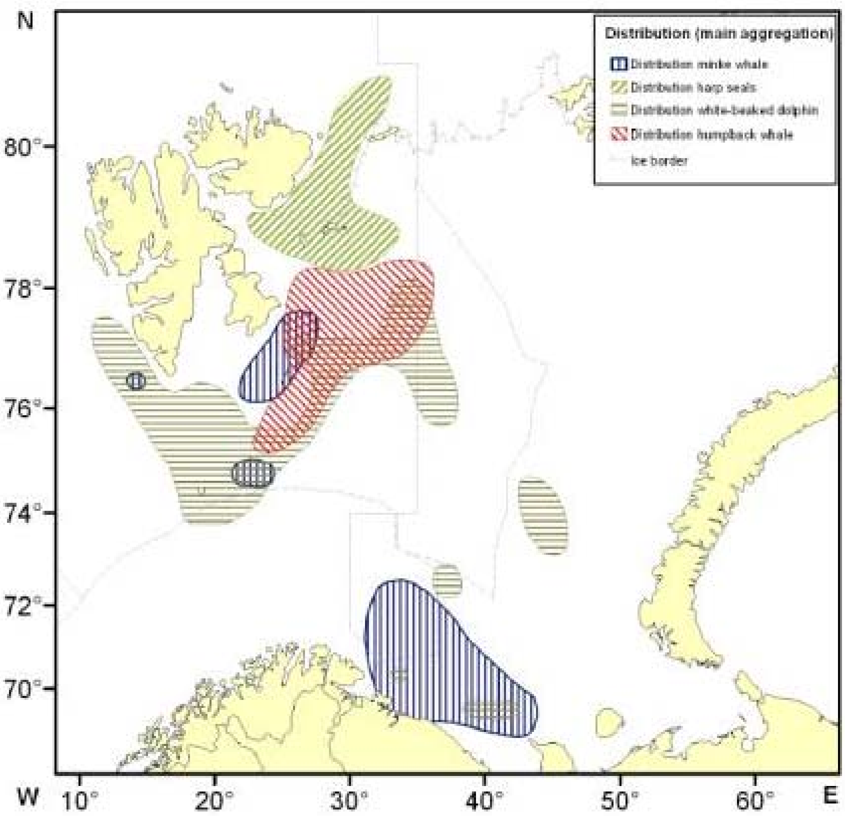


Figure 4.37. Main feeding aggregation of marine mammals in the Barents Sea in September 2005.

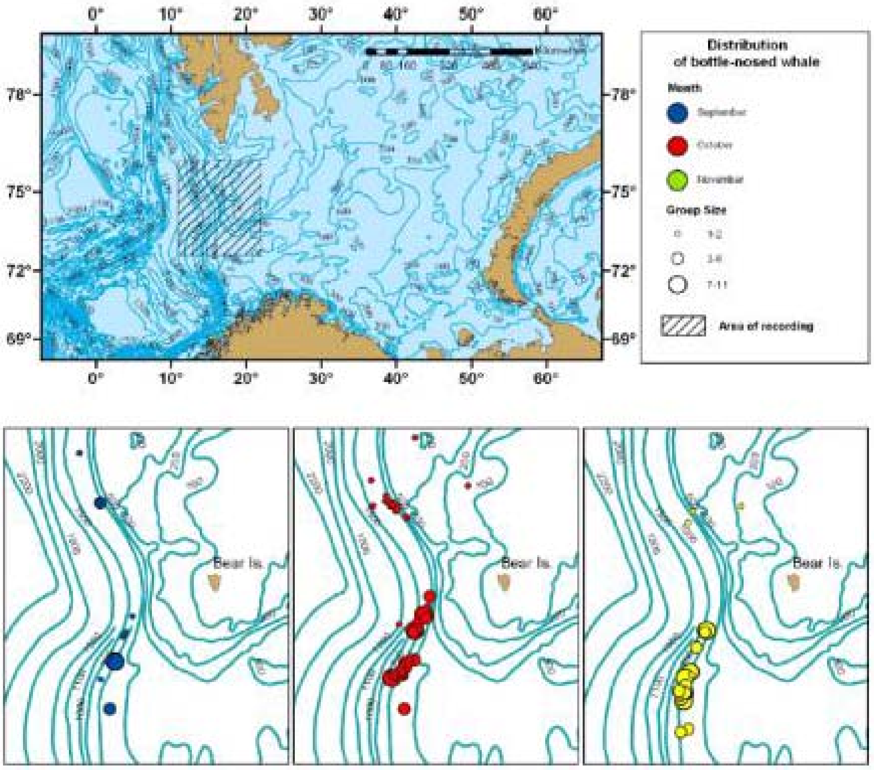


Figure 4.38. Distribution of northern bottle-nosed whales in September-November 2003-2005.

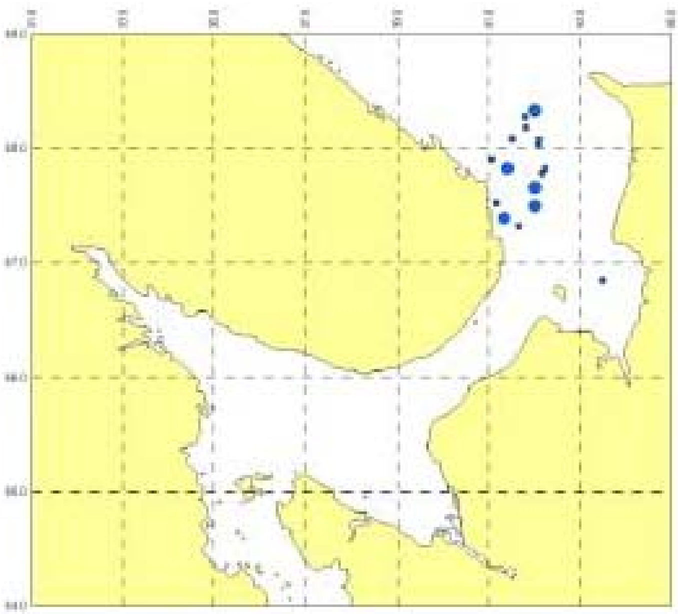


Figure 4.39. Distribution of walruses along the ice edge in April 2005.

4.6.2 Expected situation

Analyses of consumption of marine mammals in the Barents Sea for 2005 are not yet available.

5 Impacts of the fisheries on the ecosystem

5.1 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 2005, catches slightly more than 1.0 million tonnes are reported from the stocks of cod, haddock, saithe, redfish, and Greenland halibut, which is an increase of about 10% compared to 2004. 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 5.1). The major pelagic stocks are capelin, herring, and polar cod. There was no fishery for capelin in the area in 2004 and 2005 due to a stock in poor condition, and there is no directed fishery for herring in the area. 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 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 5.1 along with a description of the fisheries.

The demersal fisheries are highly mixed, usually with a clear target species dominating, and with low linkage to the pelagic fisheries (Table 5.2). 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, 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=0.004), haddock and coastal cod (p=0.059) and Northeast Arctic cod and Sebastes marinus (p=0.218) confirming the linkage in these fisheries (Figure 5.2). There is also a significant relationship between Saithe and Greenland halibut (p=0.021) although the linkage in these fisheries is believed to be small (Table 5.2). The relationships between the other fishing mortalities are scattered and inconclusive. In case of strong dependencies in fishing mortalities this method can in principle be used to produce consistent advice across species concerning fishing mortality, 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 5.2) 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 2005 the composition of cod, haddock 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 5.3-Figure ***5.6***). In the north eastern part of the Barents Sea the major part of the catches consists of cod. In the western part of the Barents Sea the Norwegian catches consists of other species 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 extends 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). However there is a difference in the composition in the eastern part in the Russian zone; the proportion of haddock in the Norwegian catches are much larger than in the Russian catches. The reason for this difference is not fully understood, but may be explained by differences in quotas for the respective fleets, although discards cannot be excluded as one of the reasons. The available data for other years and with higher resolution has not yet been gathered and compiled for a further quantitative analysis, necessary to approach consistent model based advices for all stocks.

Estimates of unreported catches of cod and haddock in 2002 - 2005 indicate that this is a considerable problem. Unreported landings are estimated at 90 000, 115 000, 117 000 and 166 000 tonnes in 2002, 2003, 2004 and 2005, respectively, *i.e.* 20-35% in addition to official landing statistics for cod, and 20738, 28946, 30469 and 40284 tonnes in 2002, 2003, 2004 and 2005, respectively, *i.e.* 18-26% in addition to official landing statistics for haddock (ICES 2006/ACFM:25). 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.

Table 5.1. Description of the fisheries by gears. The gears are abbreviated as: trawl roundfish (TR), trawl shrimp (TS), longline (LL), gillnet (GN), handline (HL), purse seine (PS), Danish seine (DS) and trawl pelagic (TP). The regulations are abbreviated as: Quota (Q), mesh size (MS), sorting grid (SG), minimum catching size (MCS), 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	LANDINGS IN 2004 (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	32599	TS, PS, DS, TP	Norwegian coast line	Q, MS, MCS, MBU, MBN, C, RS, RA
Cod	TR, GN, LL, HL	all year	580000	TS, PS, TP, DS	North of 62°N, Barents Sea, Spitsbergen	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Wolffish[1]	LL	all year	21081	TR, (GN), (HL)	North of 62°N, Barents Sea, Spitsbergen	Q, MB
Haddock	TR, GN, LL, HL	all year	116293	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	161916	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[2]	LL, GN	Seasonal	18762	TR	deep shelf and at the continental slope	Q, MS, RS, RG, MBH, MBL
Sebastes mentella	No directed fishery	all year	4914	TR	deep shelf and at the continental slope	C, SG, MB
Sebastes marinus	GN, LL,HL	all year	7293	TR	Norwegian coast	SG, MB MCS, MBU, C
Shrimp	TS	all year	41800[3]		Spitsbergen, Barents Sea, Coastal	ED, EF, SG, C, MCS

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

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

[3]The total catch in 2003

Table 5.2. Flexibility in coupling between the fisheries. Fleets and impact on the other species (H, high, M, medium, L, low and 0, nothing). The 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	

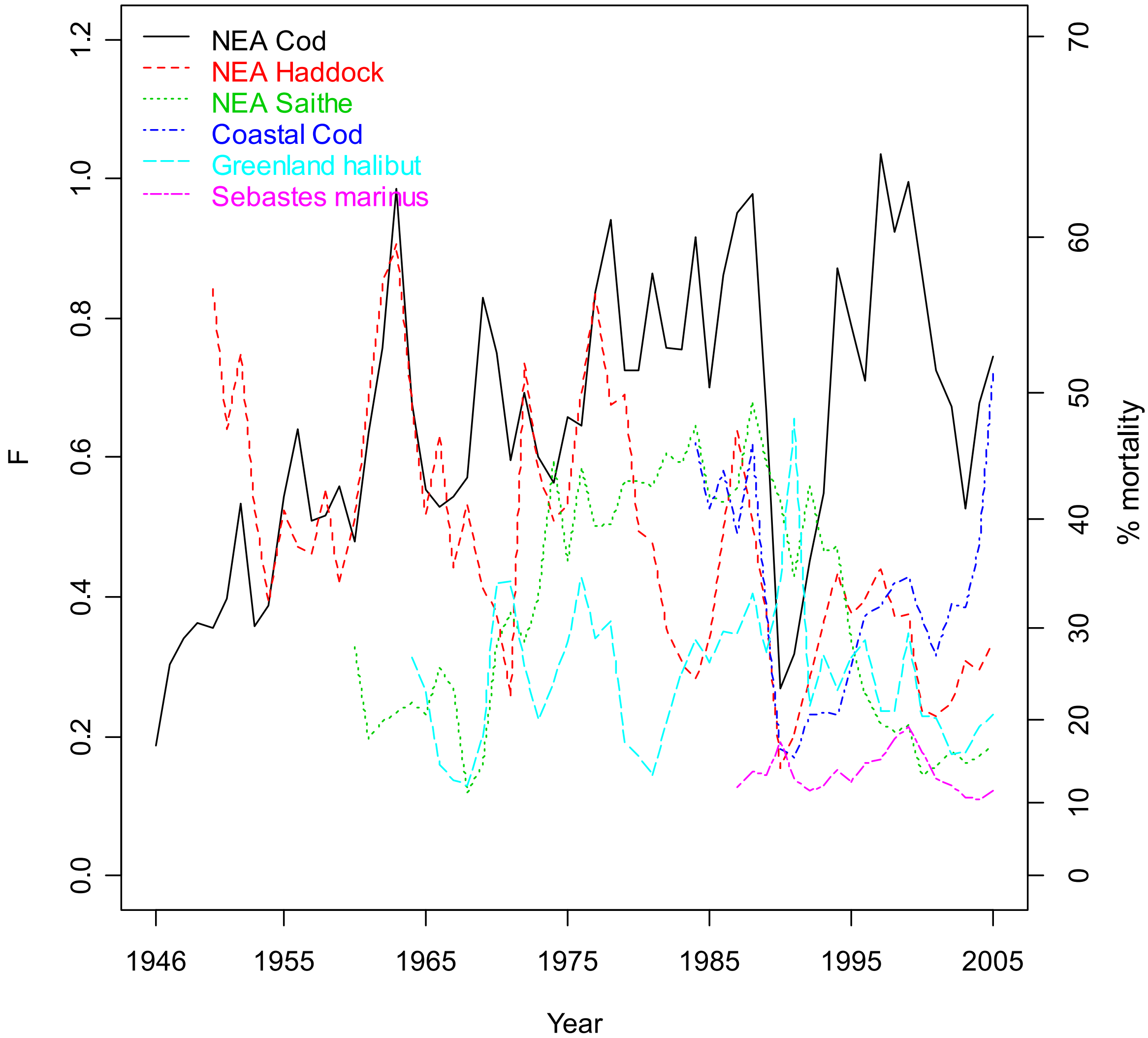


Figure 5.1. Time series of annual average fishing mortalities for Northeast Arctic cod (time period 1946-2005, average for ages 5-10), Northeast Arctic haddock (time period 1950-2005, average for ages 4-7), Northeast Arctic saithe (time period 1960-2005, average for ages 4-7), coastal cod (1984-2005, average for ages 4-7) and Greenland halibut (time period 1964-2005, average for ages 6-10) and Sebastes marinus (time period 1987-2005, average for ages 12-19).

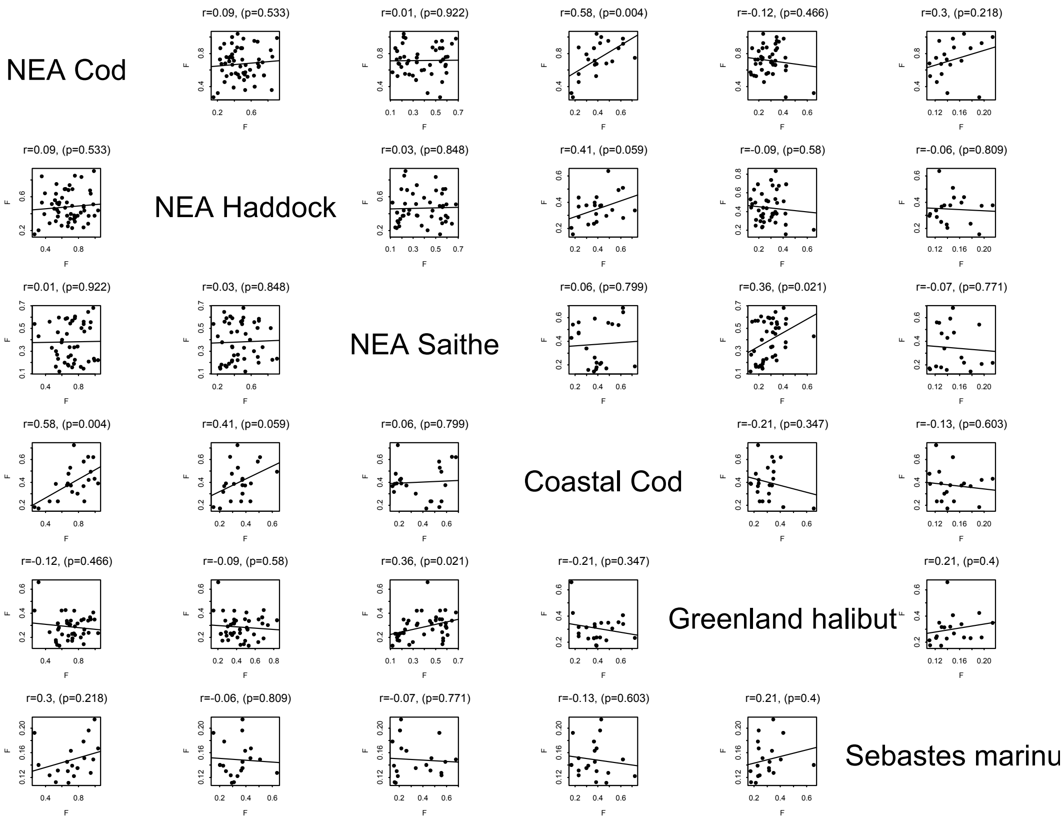


Figure 5.2. Pairwise plots of annual average fishing mortalities for overlapping time periods for Northeast Arctic cod (time period 1946-2005, average for ages 5-10), Northeast Arctic haddock (time period 1950-2005, average for ages 4-7), Northeast Arctic saithe (time period 1960-2005, average for ages 4-7), coastal cod (1984-2005, average for ages 4-7), Greenland halibut (time period 1964-2005, average for ages 6-10) and Sebastes marinus (time period 1987-2005, average for ages 12-19). The correlation and the corresponding p-value are given in the legend.

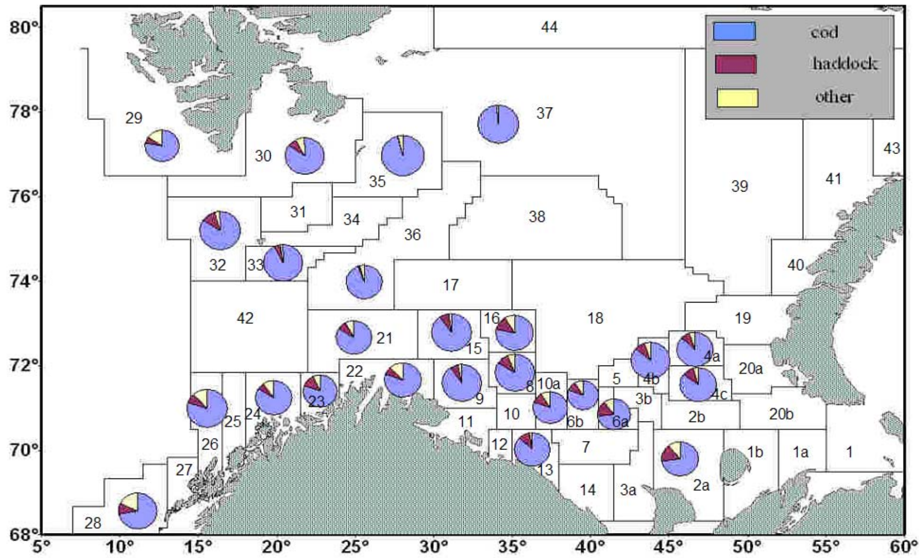


Figure 5.3. Relative distribution of composition of cod, haddock and other species taken by Russian bottom trawl in 2005 per main areas for the Russian strata system by weight.

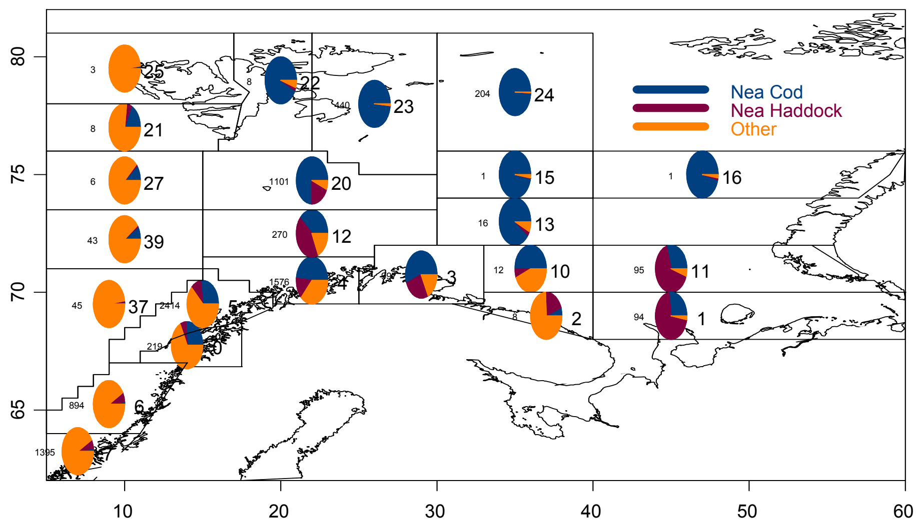


Figure 5.4. Relative distribution of composition of cod, haddock and other species taken by Norwegian bottom trawl in 2005 per main areas for the Norwegian strata system. The large numbers to the right of the pie diagrams are the name of the stratum, while the small numbers to the left is the number of vessel days recorded in the area.

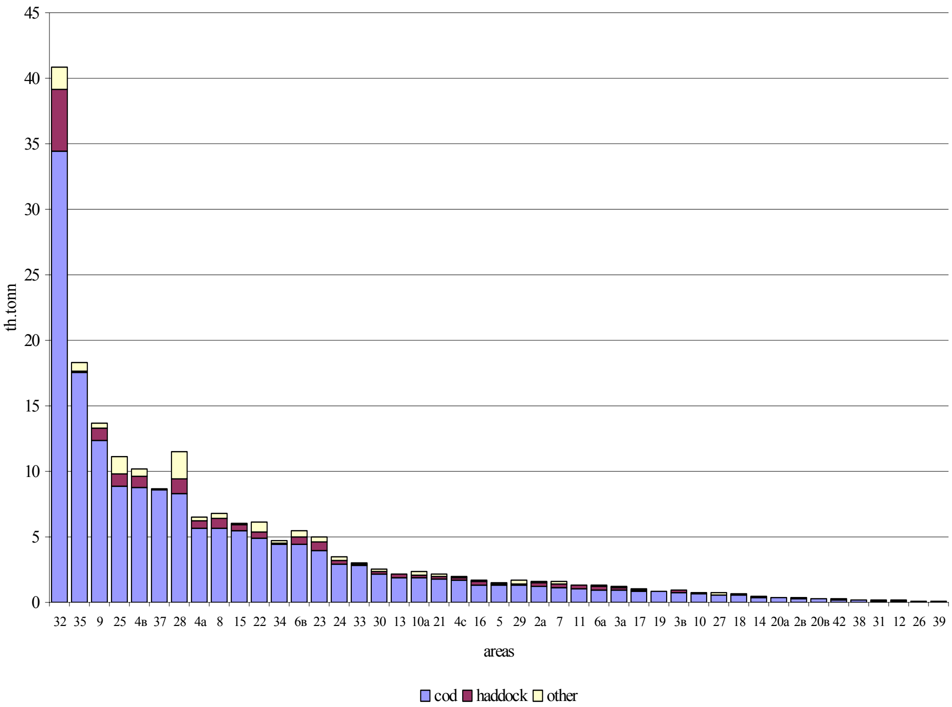


Figure 5.5. The Russian catch of cod, haddock and other species taken by bottom trawl by main statistical areas in 2005, thousand tons. The statistical areas correspond to the areas shown in Figure 5.3.

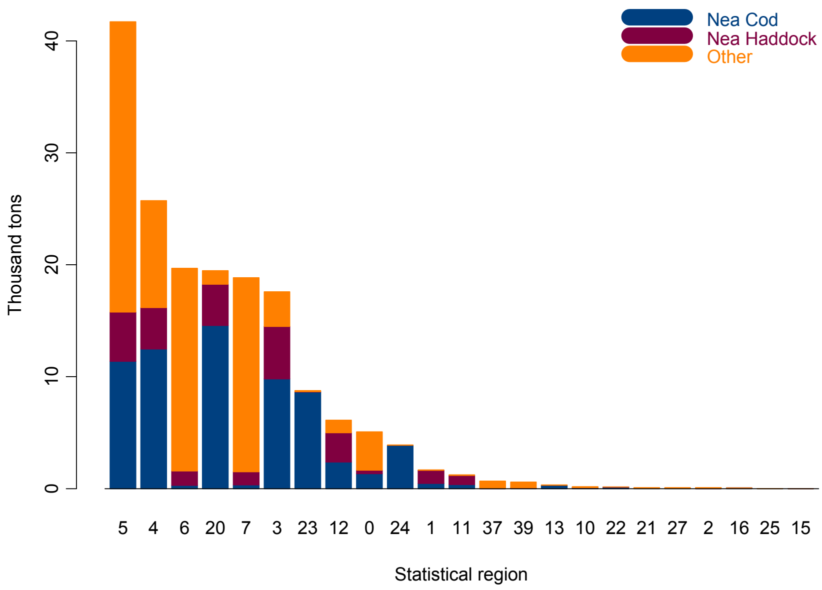


Figure 5.6. The Norwegian catch of cod, haddock and other species taken by bottom trawl by main statistical areas in 2005, thousand tons. The statistical areas correspond to the areas shown in Figure 5.4.

5.2 Impact of fisheries

In order to conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. However, its qualitative effects have been studied to some degree. The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. 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.

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. 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.

6 Levels and impact of pollution on the ecosystem

6.1 Contaminants in fish

The concentrations of persistent organic pollutants (POPs) in fish from the Barents Sea are low compared to fish collected closer to more densely populated areas along the European coast, like the Baltic Sea and the southern North Sea. Figure 6.1 show the average concentrations of POPs in fish collected from the Barents Sea during 2003-2004. The results presented are from routine monitoring activities carried out by the Institute of Marine Research (IMR).

Every third year samples of cod and haddock are analysed for concentrations of polyaromatic hydrocarbons (PAH) in fillet. The last sampling took place autumn 2005. This monitoring forms part of the monitoring carried out by the oil companies operating in Norwegian offshore areas including the Barents Sea. The major aim is to document whether the quality of the fish is affected by discharges from the offshore petroleum industry. The results generally shows that fish fillet contain very low background concentrations of PAH. This can be explained by the generally low background concentrations of PAH in the Barents Sea, and the fact that fish exposed to PAH has an efficient system to metabolize and excrete most of the compounds.

Fish from the Barents Sea has been analysed for the content of cesium-137 (^{137}Cs). Important sources are global fallout, fallout from the Chernobyl accident and fallout from nuclear weapons testing near Novaya Zemlya. In addition, there have been direct discharges from nuclear installations along the Russian rivers Ob and Yenisey, which drain into the Kara Sea, plus discharges from the nuclear reprocessing plants Sellafield (UK) and La Hague (F). Figure 6.2 shows the levels of 137Cs in different species of fish. The levels are generally low and represent, to our knowledge, no threath to human health.

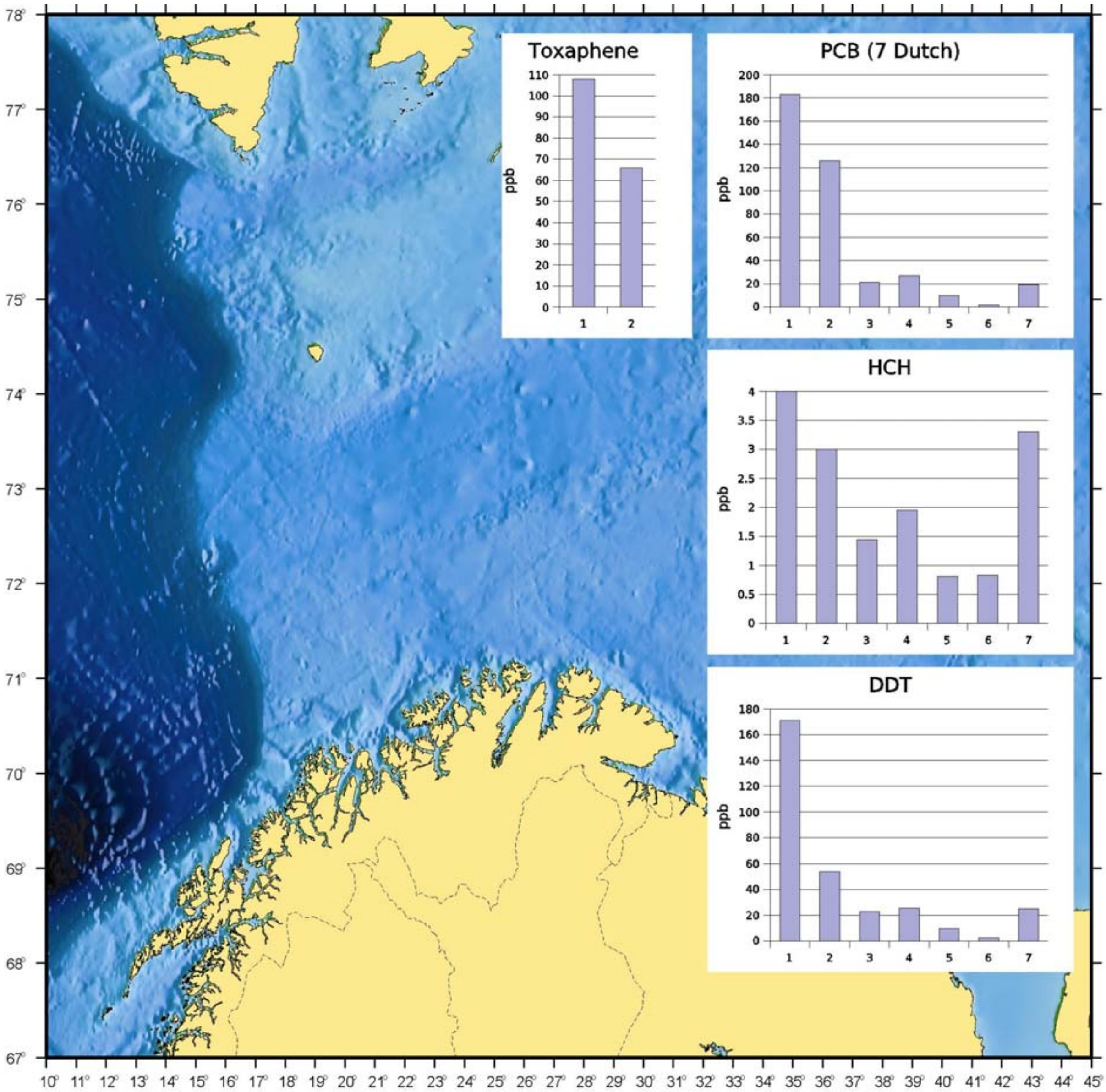


Figure 6.1. Average concentrations (ng/g wet weight) of PCBs (sum of CB congeners no. 28, 52, 101, 118, 138, 153, 180), DDTs (sum p,p´-DDT, p,p´-DDE, p,p´-DDD), HCHs (sum alpha-, beta-, gamma-HCH) and Toxaphene (sum Parlar no. 26, 50,62) in cod (Gadus morhua) (1), haddock (Melanogrammus aeglefinus) (2), redfish (Sebastus marinus) (3), Greenland halibut (Reinhardtius hippoglossoides) (4), long rough dab (Hippoglossoides platessoides) (5), capelin (Mallotus villosus) (6) and polar cod (Boreogadus saida) (7). Values are for liver, except for capelin where whole fish was analysed.

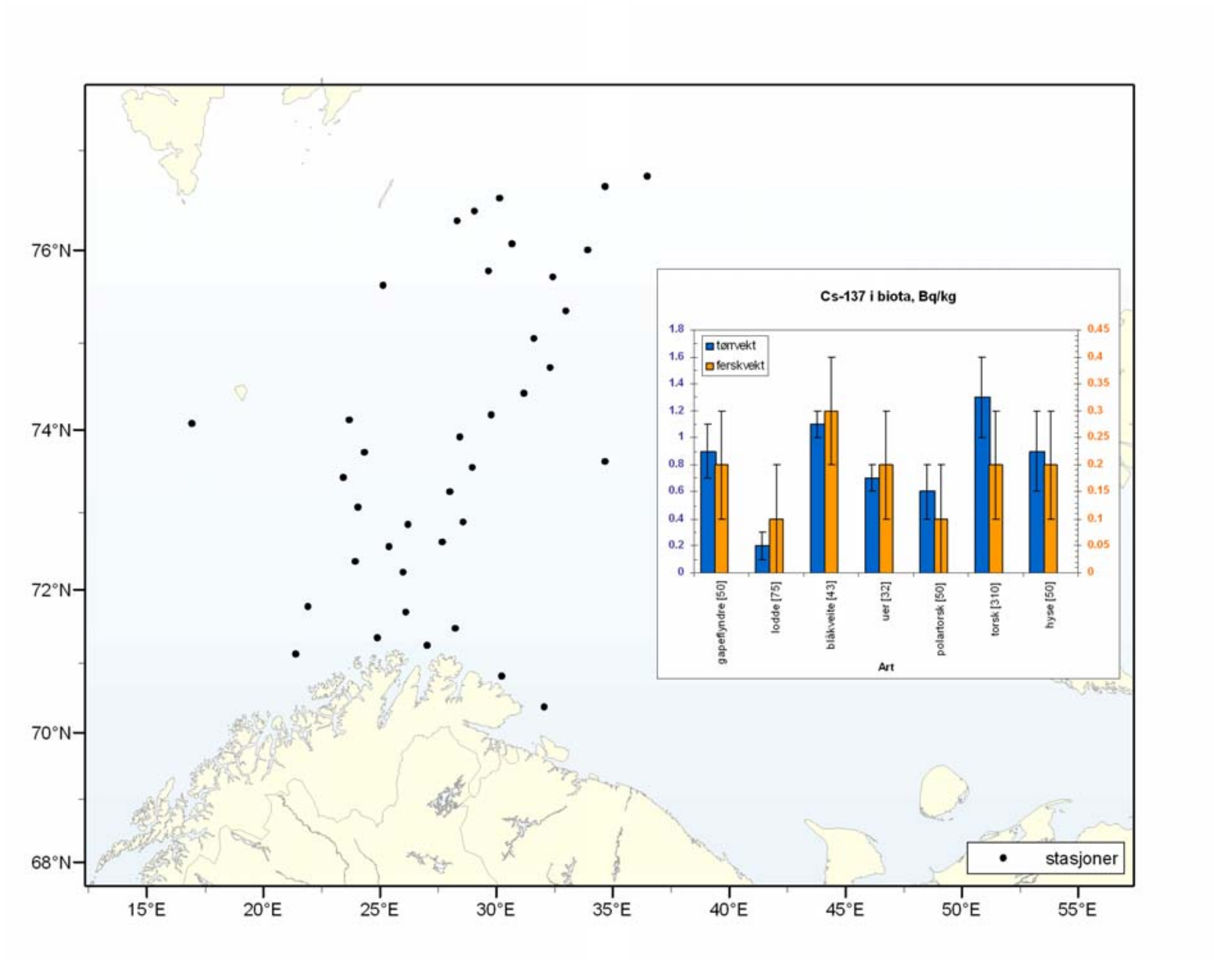


Figure 6.2. ^{137}Cs in fish fillet from the Barents Sea in Bq/kg (blue bars show dry weight and orange bars show wet weight). Average levels and ranges.

6.2 Contaminants in sediments

Institute of Marine Research has analysed the levels of PAH in sediments collected 2003-2004 from the Barents Sea and the Norwegian Sea. Figure 6.3shows the levels of PAH in surface sediments (0-1cm). The sediment stations in the southern and central parts of the Barents Sea generally contain lower concentrations of PAH that surface sediments in the northern areas close to Spitsbergen. This may both be due to contributions from seepage and the coal rich geological structures around Spitsbergen.

During the last ten years sediments from approximately 200 stations from the area have been analysed for ^{137}Cs and the levels vary from below detection to 9.7 Bq/kg dry weight. Figure 6.4 shows the levels of ^{137}Cs in surface sediments collected from the Barents Sea in 2003 and the levels ranged from 0.5-4.4 Bq/kg wet weight.

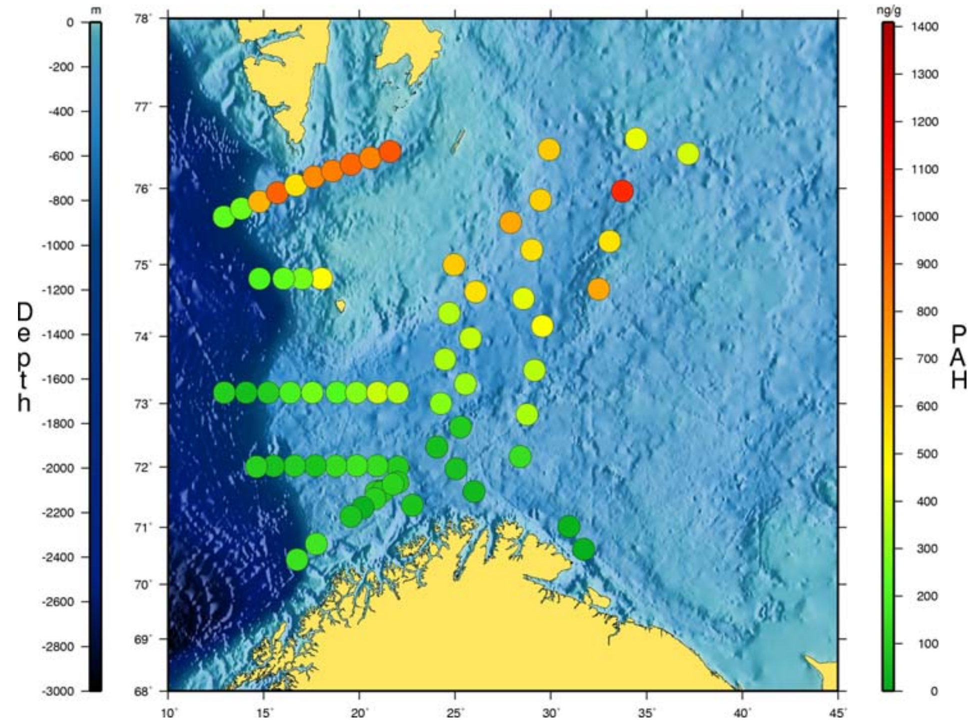


Figure 6.3. PAH concentrations (ng/g wet weight) in surface sediments (0-1 cm) collected 2003-2004. PAH: Sum of phenanthrene, anthracene, acenaphthylen, acenapthene, fluorene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b,j,k)fluoranthene, benzo(e)pyrene, benzo(a)pyrene, perylene, indeno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, benzo(g,h,i)perylene.

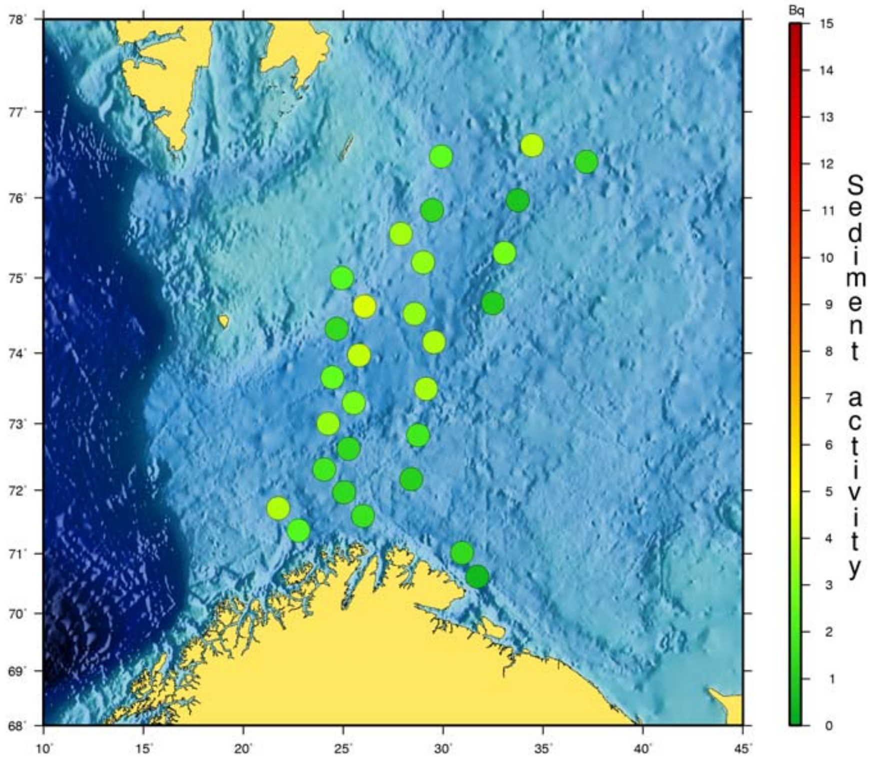


Figure 6.4. ^{137}Cs (Bq/kg dry weight) in surface sediments (0-1 cm) collected 2003.

7 Ecosystem information with potential for implementation in fisheries management

7.1 Overview

The main method for including ecosystem information into fisheries management decisions is through mathematic modelling. There are many examples of application of regression models for the prognosis 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 models designed to improve fisheries management in the Barents Sea based on species interactions stated in the mid 1980s. At the first stage, the work was focused on models that included maximum number of species interacted according to their trophic relations. This approach was used in 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 species interaction of cod in the Barents Sea and can be useful to solve some theoretical problems of multispecies harvest management. However, the use of these models for practical tasks of fisheries management is limited by 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 more simple, in structural sense, models have been prioritised. An overview of multispecies models for the Barents Sea currently in use is given below.

At present, predation by cod on cod, haddock and capelin is included in the assessment for those stocks. However, capelin is the only of these stocks for which predation by cod is modelled 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.

7.2 Multispecies models

7.2.1 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 modelled, 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.

7.2.2 Bifrost

The Bifrost (Boreal integrated fish resource optimization and simulation tool) is a multispecies model for the Barents Sea (Tjelmeland and Lindstrøm, 2005) with main emphasis on the 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 parameterisation 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.

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 modelled through the recruitment function for capelin. Bifrost is also used to evaluate cod-capelin-herring multispecies harvesting control rules.

7.2.3 STOCOBAR

The STOCOBAR (STOck of Cod in the BARents Sea) is a model that describes stock dynamics of cod in the Barents Sea, taking into account its 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 on growth rate, maturation, consumption and cannibalism of cod have been presented at AFWG since 2002.

The STOCOBAR model is spatially unstructured, and the time step can beset 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 and juveniles of haddock and cod). All species except for shrimp and krill are divided in age groups. The recruitment function is use for cod only. Estimation of the influence of a complex of ecosystem factors on the year-to-year dynamics of cod population parameters are realized in the model by using stochastic ecosystem scenarios. Such scenarios based on the temperature determine the development of biological processes (dynamic of population of prey-species for cod). Temperature stochastic sceneries for modelling long-term runs are developed on basis of historical data from the Kola section, also taking into account autocorrelations.

The first version of STOCOBAR was developed at PINRO in 2001. The current work on improvement of this model is continued. 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 (2005-2007).

7.2.4 GADGET

The model (www.hafro.is/gadget; Begley and Howell, 2004), developed during the EU project dst[2] (2000-2003), will be used for modeling the interactions between cod, herring, capelin and minke whale in the Barents Sea during the EU project BECAUSE (2004-2007). The modeling approach taken has many similarities to the MULTSPEC approach (Bogstad et al., 1997). Further, the modeling of recruitment processes in Gadget will be enhanced during the EU project UNCOVER (2006-2010).

7.3 Process models

7.3.1 Recruitment

Predictions of the recruitment in fish stocks are essential for predicting harvesting of the 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 gives the opportunity to make a prediction. (e.g. Bulgakova, 2005; Stiansen *et al*., 2005; Titov *et al*., 2005).

7.3.2 Maturation

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. One approach to investigating the links between food availability and maturation is to examine the correlation between weight- and maturity-at-age. Weight- and maturity-at age were converted to weight- and maturity-at-length using age/length keys as described by Marshall *et al*. (2004). 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.

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 the 1985-2001 period there is a consistently significant, positive relationship between liver weight and proportion mature. A modeling approach to implement this knowledge in the assessment could be developed. This subject was described in more details in last years' AFWG report (ICES 2005/ACFM:20).

7.3.3 Consumption models

When calculating the prey consumption by a given predator, both the overall consumption level and the prey composition in the diet are used. The prey composition is usually derived from stomach content data, while the overall consumption level can be calculated using two approaches:

1) A bioenergetic approach (as is usually the case for marine mammals and seabirds as predators)
2) By combining data on stomach content weight with models for gastric evacuation rate, based on experiments (usually used for fish).

As shown in Johannesen *et al*. (2006), different methods of type 2) to calculating cod consumption give significantly different results, and thus further work is needed.
It is also important to compare results from these two approaches, as they supplement each other. For cod both methods have been applied (e.g. Ajiad 1996, Bogstad and Mehl, 1997), and the results were in good agreement with each other.

7.4 Expected impact of ecosystem factors on fish stock dynamics in the Barents Sea

7.4.1 Prediction of NEA cod growth rate

The Northeast arctic cod is characterized by significant year-to-year variations in the growth rate. In different years the mean weight of fish at the same age may differ 2-3 times. The main factors influencing cod growth are water temperature, food supply and cod population abundance.

The STOCOBAR model gives prognoses of the mean weight of cod in the beginning of the year. Figure 7.1 shows the consistency between observed and simulated weight of cod from historical data from this model.

Table 7.1 presentes prognosis of weight of cod on 2005-2008 from the STOCOBAR model, where 2004 was used as initial year. The model parameters were estimated on historical data 1984-2004. For the prognosis the assessment of current and expected capelin stock state were used derived from 2006 report of joint Russian-Norwegian meeting to assess the Barents Sea capelin stock (Anon., 2006b). For the periods 2007-2008 and 2006-2008 an average of the previous three years were used for the temperature and recruitment of cod at age 1, respectively.

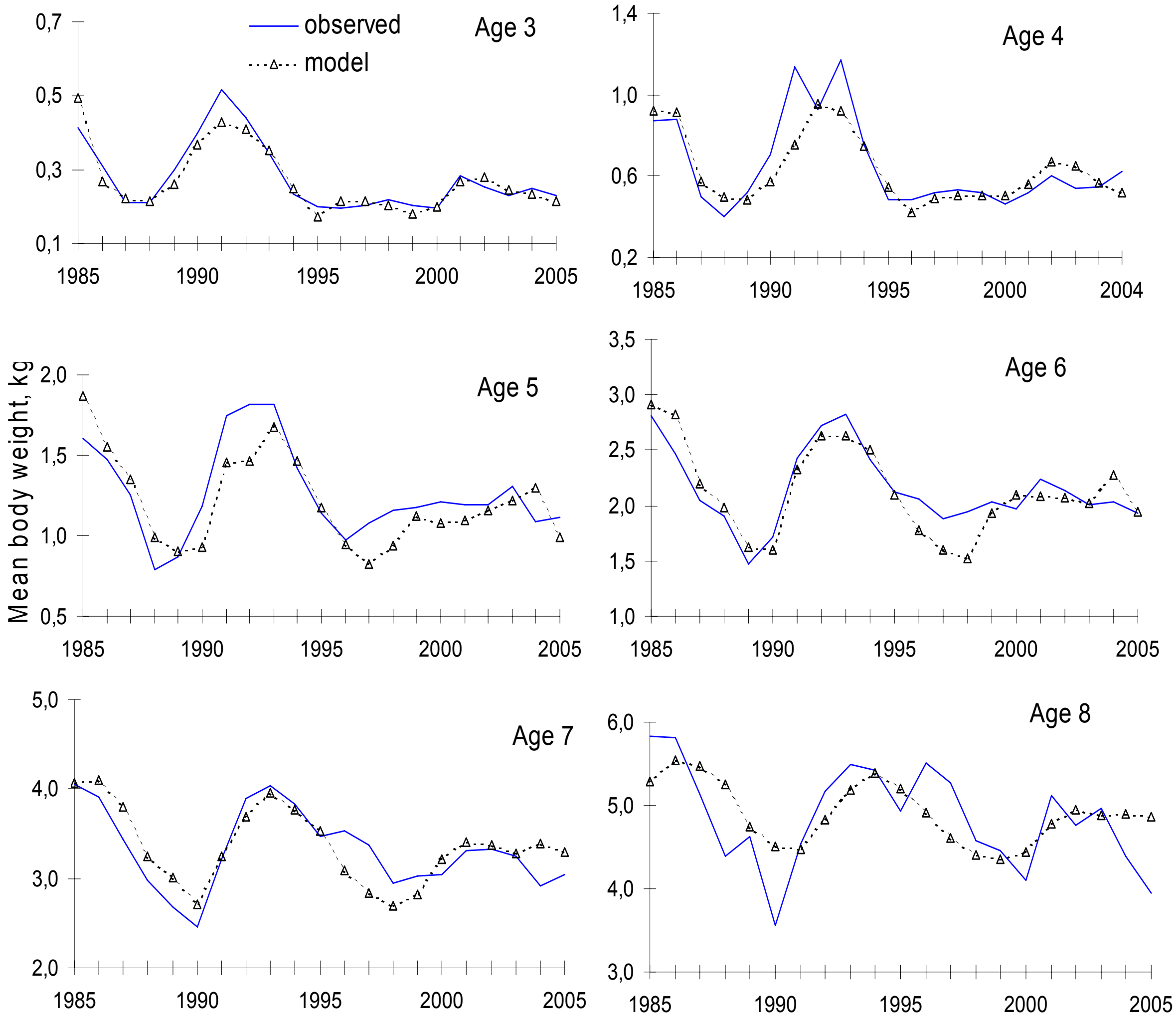


Figure 7.1. Consistency between the observed and simulated cod individual weight in the STOCOBAR model.

Table 7.1. Prognoses of mean weight at age of NEA cod at the 2005-2008 by the STOCOBAR model, together with the observations in 2005–2006.

	2005		2006		2007	2008
Age	Observed	Model	Observed	Model	Model	Model
2	0,058	0,062	0,71	0,083	0,085	0,079
3	0,231	0,230	0,256	0,275	0,285	0,277
4	0,624	0,583	0,602	0,567	0,636	0,658
5	1,118	1,024	1,201	1,114	1,094	1,214
6	1,932	1,816	2,009	1,886	1,923	2,037
7	3,046	3,231	3,114	3,226	3,111	3,359
8	3,955	4,449	4,427	4,973	4,793	4,878
9	5,811	6,293	6,030	6,796	6,870	7,123
10	8,289	8,921	8,0,37	9,330	9,208	9,712

7.4.2 Prediction of NEA cod recruitment.

Prognosis estimates from the recruitment models are shown in ***Figure 7.2*** and ***Table 7.2***, together with estimates from assessment (ICES 2006/ACFM:25). There is relatively good correspondence between the various methods concerning recruitment in 2006, expect that the estimate from Gadget is about half of the estimates from the other methods. The estimates for 2007 and 2008 from various methods are quite close.

Table 7.2. Overview of available recruitment models prognoses, together with the 2006 assessment estimates from the AFWG assessment (ICES 2006/ACFM:25). 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	2006 Prognoses	2007 Prognoses	2008 Prognoses	Unit
Titov (WD 16, AFWG 2005)	NEA cod	Recruits (age 3)	4	Before assessment	555 [*]	951 [*]		$*10^6$
Bulgakova (WD20, AFWG 2005)	NEA cod	Recruits (age 3)	3	Before assessment	703 [*]	532 [*]		$*10^6$
Stiansen et al., WD15	NEA cod	Recruits (age 3)	2 (3 [1])	November (March [1])	**478**	**578**	**565** [1]	$*10^6$
Stiansen et al., WD15	NEA cod	Recruits (age 3)	1 (2 [1])	November (March [1])	**416**	**434** [1]		$*10^6$
Stiansen et al., WD15	NEA cod	Recruits (age 3)	0 (1 [1])	November (March [1])	**440** [1]			$*10^6$
Gadget Assessment 2006	NEA cod	Recruits (age 3)	1	At assessment	224			$*10^6$
RCT3 Assessment 2006	NEA cod	Recruits (age 3)	3	At assessment	431	533	546	$*10^6$
RCT3 Assessment 2005	NEA cod	Recruits (age 3)	3	At assessment	478	574		$*10^6$

[1] Based on prognosis estimate of capelin maturing biomass for October 1 2005 of 272 000 tonnes, thereby allowing for an additional year.

[*] Numbers were calculated before the 2005 assessment (ICES, 2005), and have not been updated for in the 2006 assessment.

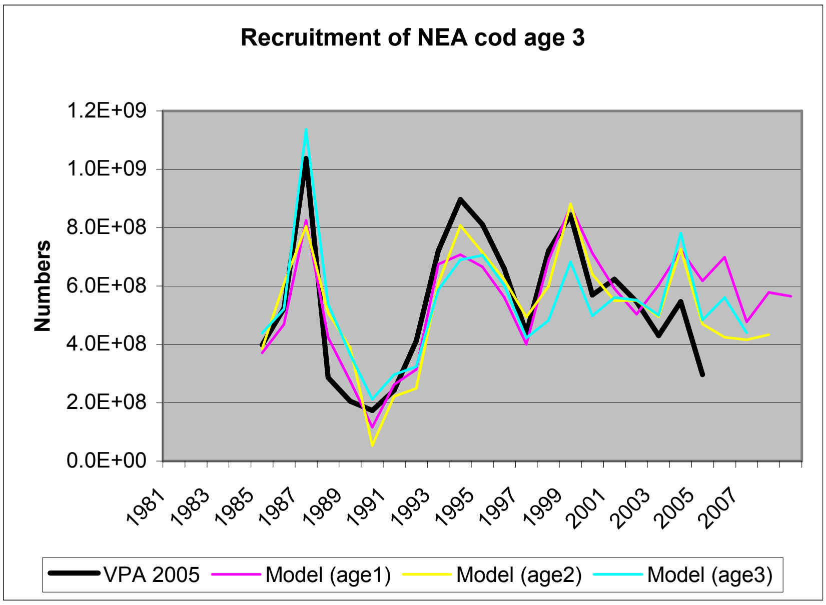


Figure 7.2 Recruitment of NEA cod. The figure shows the number of age 3 cod (black line) together with three different multiple regression models (yellow, blue and red line). The regression models give prognoses for 2006-2008 (Stiansen et al., 2005).

7.4.3 Expected stock parameters based on qualitative analysis of ecosystem impact factors

An alternative approach for looking at the future development of the commercial fish stocks 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 overall effect, together with the impact factors and the stock parameters are shown in Table 7.3.

Table 7.3.Qualitative analysis of the effects of ecosystem impact factors on some stocks in the Barents Sea for 2006.

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

H – high, M – medium and L – low expectation of biological parameters.

+ positive (++ strongly positive)) influence of ecosystem parameters on biological parameters;

+ – Influence of ecosystem parameter on biological parameter without clear positive or negative effects;

– negative (-- strongly negative) influence of ecosystem parameters on biological parameters;

? knowledge are not available.

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9 References

ACIA, (2005). Arctic Climate Impact Assessment. Cambridge University Press, 1042 pp.

Ajiad, A.M., (1996). 'Assessing growth of Northeast Arctic cod by a bioenergetics model'. ICES C. M. 1996/G:16, 16 pp.Andriashev, A.P., (1954). 'Fishes of the Northern Seas of USSR.' In: Israel Program for Scientific Translations, Jerusalem.

Anker-Nilssen, T., Bakken, V., Strøm, H., Golovkin, A.N., Bianki, V.V. and Tatarinkova, I.P., (2000). 'The status of marine birds breeding in the Barents sea region', Norsk Polarinstitutt rapport 113, 213 pp.

Anon., (2004). 'Survey report from the joint Norwegian/Russian Ecosystem Survey in the Barents Sea August-October 2004', Vol. I. IMR-PINRO Joint Report series, No. 3/2004. ISSN 1502-8828, 71 pp.

Anon., (2005). 'Survey report from the joint Norwegian/Russian Ecosystem Survey in the Barents Sea August-October 2005', Vol. I. IMR-PINRO Joint Report series, No. 3/2005. ISSN 1502-8828, 99 pp.

Anon., (2006a). 'Status of biological resources in the Barents Sea and North Atlantic for 2006', V.N.Shibanov (Ed.). Collected Papers. PINRO Press, Murmansk, 99 pp. (in Russian).

Anon., (2006b). Report from the 2006 joint Russian-Norwegian meeting to assess the Barents Sea capelin stock, Kirkenes, Norway, September 30 - October 3 2006.

Aschan, M., (2000). 'Spatial Variability in Length Frequency Distribution and Growth of Shrimp (*Pandalus borealis* Krøyer 1838) in the Barents Sea', J. Northw. Atl. Fish. Sci., Vol. 27, 93-105.

Barrett, R.T., Anker-Nilssen, T., Gabrielsen, G.W. and Chapdelaine, G., (2002). 'Food consumption by seabirds in Norwegian waters'. ICES Journal of Marine Science (ICES J. Mar. Sci.). Vol. 59, no. 1, pp. 43-57.

Begley, J. and Howell, D., (2004). 'An Overview of Gadget, the Globally applicable Area-Disaggregated General Ecosystem Toolbox', ICES C.M. 2004/FF:13, 16 pp.

Belikov, S.V., Sokolov, A.M. and Dolgov, A.V., (2004). 'Blue whiting', In : Investigations by PINRO in the Spitsbergen archipelago area. Murmansk, PINRO Press, 166-177. (in Russian)

Bjørge, A. and Kovacs, K.M., (sci. eds.). 'Report of the working group on seabirds and mammals. The Scientific Basis for Environmental Quality Objectives (EcoQOs) for the Barents Sea Ecosystem', (in prep.) Norway, 2005.

Bochkov, Yu.A., (1982). 'Water temperature in the 0-200m layer in the Kola-Meridian in the Barents Sea, 1900-1981', Sb. Nauchn. Trud. PINRO 46, 113-122.

Bochkov, Yu.A., (2005). 'Large-scale variations in water temperature along the «Kola meridian» section and their forecasting. 100 years of oceanographic observations along the Kola Section in the Barents Sea'. Papers of the international symposium. Murmansk, PINRO: 201-216.

Bogstad, B., Hiis Hauge, K. and Ulltang, Ø., (1997). 'MULTSPEC – A Multi-Species Model for Fish and Marine Mammals in the Barents Sea', J. Northw. Atl. Fish. Sci. 22, 317-341.

Bogstad, B. and Mehl, S., (1997). 'Interactions between Atlantic cod (Gadus morhua) and its prey species in the Barents Sea', Forage Fishes in Marine Ecosystems. Alaska Sea Grant College program. AK-SG-97-01, 591-615.

Boitsov V.D. and Karsakov A.L., (2005). 'Long-term projection of water temperature to be used in the advance assessment of the Barents Sea productivity'. Ecosystem dynamics and optimal long-term harvest in the Barents Sea fisheries Proceeding of the 11th

Russian-Norwegian Symposium. Papers of the international symposium. Murmansk, PINRO: 324-330.
Bulgakova, T., (2005). 'To recruitment prognosis of NEA cod'. Working document #20 in: Report of the Arctic Fisheries Working Group', Murmansk, Russia, April 19-28, 2005. ICES C.M. 2005/ACFM:20, 564 pp.
Daan, N., Heessen, H.J.L. and Pope, J.G., (1994). 'Changes in the North Sea cod stock during the twentieth century'. ICES Mar. Sci. Symp., 198: 229-243.
Dalpadado, P., (2002). 'Inter-specific variations in distribution, abundance and possible life cycle patterns of Themisto spp. (Amphipoda) in the Barents Sea', Polar Biology 25, 656-666.
Dalpadado, P. and Bogstad, B., (2004). 'Diet of juvenile cod (age 0-2) in the Barents Sea in relation to food availability and cod growth', Polar Biology 27, 140-154.
Dolgov A.V., (2000). 'Feeding and food consumption by the Barents Sea predatory fishes in 1980-1990s', ICES CM 2000/Q:02, 17pp.
Dolgov A.V., (2002). 'The role of capelin (Mallotus villosus) in the foodweb of the Barents Sea', ICES J. Mar. Sci., 59, 1034-1045. (in Russian)
Dolgov A.V., (2004). 'Species composition of ichthyofauna and ichtyocoenosis structure of the Barents Sea', Izvestia PINRO, Vol. 137, 177-195.
Dolgov A.V., (2005). 'Feeding and Food Consumption by the Barents Sea Skates', J. Northw. Atl. Fish. Sci, Vol. 35: 495-503. (E-J. Northw. Atl. Fish. Sci., 2005, Vol. 35, art. 34, 10 pp.)
Dolgov A.V. and Drevetnyak, K.V., (1993). 'Some peculiarities of feeding and feeding interrelations of deepwater redfish (Sebastes mentella) in the Barents and Norwegian seas', ICES C.M. 1993/G:60, 14 pp.
Dolgov A.V. and Drevetnyak, K.V., (1995). 'Feeding of young Sebastes mentella Travin in the Barents and Norwegian seas. Precision and relevance of pre-recruit studies for fishery management related to fish stocks in the Barents sea and adjacents waters', Proceedings of the sixth IMR-PINRO Symposium, Bergen, June 14 – 17, 1994. (Ed. A.Hylen) - IMR, Norway, 1995, 129-134.
Drobysheva, S.S., (1967). 'The role of specific composition in the formation of the Barents Sea euphausiid abundance', Trudy PINRO. Vol. 20, 195-204 (in Russian).
Drobysheva, S.S., (1994). 'The Barents Sea euphausiids and their role in the formation of fishing biological production', Murmansk: PINRO Press, 1994, 139pp. (in Russian).
Drobysheva, S.S., Nesterova, V. and Zhukova, N., (2003). 'Abundance dynamics of the Barents Sea euphausiids and their importance as a component of cod food supply', WD4, ICES Arctic Fisheries Working Group, Pasaia, Spain April 23 – May 2, 2003, 11pp.
Drobysheva, S.S. and Yaragina, N.A., (1990). 'The euphausiids importance in the feeding of the Barents Sea fishes', In: Food supply and trophic interrelationships of the fishes in the North Atlantic. PINRO Press, 184-206. (in Russian)
Ekman, S., (1953). 'The boreal fauna of the North Atlantic', Zoogeography of the sea. Sidgwick & Jackson, London
Fauchald, P. and Erikstad, K. E., (2002). ‚Scale-Dependent Predator-Prey Interactions: the Aggregative Response of Seabirds to Prey Under Variable Prey Abundance and Patchiness'. Marine Ecology Progress Series, 231: 279-291.
Filin, A., (2005). STOCOBAR model for simulation of the cod stock dynamics in the Barents Sea considering the influence of ecosystem factors'. Proceedings of the 11th Russian-Norwegian Symposium: 'Ecosystem dynamics and optimal long-term harvest in the Barents Sea fisheries', Murmansk, Russia August 15 – 17, 2005. 11 pp. IMR/PINRO Joint Report Series 2/2005. Institute of Marine Research, Bergen.

Filin, A.A. and Tjelmeland, S., (2005). ‘Ecosystem approach to estimation of long-term yield of cod in the Barents Sea’, pp 130-137 in: Shibanov, V., (Ed.) ‘Proceedings of the 11th Joint Russian-Norwegian Symposium: Ecosystem dynamics and optimal long-term harvest in the Barents Sea fisheries’, Murmansk, Russia August 15 – 17, 2005. IMR/PINRO Joint Report Series 2/2005. Institute of Marine Research, Bergen.

Folkow, L.P., Haug, T., Nilssen, K.T. and Nordøy, E.S., (2000). ‘Estimated food consumption of minke whales *Balaenoptera acutorostrata* in Northeast Atlantic waters in 1992-1995’, NAMMCO Scientific Publications 2, 65-80.

Fossheim, M. and Nilssen, E.M., (2002). ‘Identification of fish communities in the Barents Sea: is there a faunal discontinuity across the Polar front?’ ICES CM L:17.

Gjøsæter, H. and Bogstad, B., (1998). ‘Effects of the presence of herring (Clupea harengus) on the stock-recruitment relationship of Barents Sea capelin (Mallotus villosus)’, Fish. Res., 38, (1): 57-71.

Grebmeier, J.M. and Barry, J.P., (1991). ‘The influence of oceanographic processes on pelagic-benthic coupling in polar regions: a benthic perspective’, J. Mar. Sys. 2, 495-518.

Grebmeier, J.M., Smith, W.O. and Conover, R.B., (1995). ‘Biological processes on Arctic continental shelves: ice-ocean-biotic interactions’, pp 231-261 In: Smith, W.O. and Grebmeier, J.M. (Eds.), Arctic Oceanography: Marginal Zones and Continental Shelves. American Geophysical Union, Washington, D.C.

Gjøsæter, H., Dalpadado, P. and Hassel, A., (2002). ‘Growth of Barents Sea capelin (Mallotus villosus Müller) in relation to zooplankton abundance’, ICES J. Mar. Sci. 59:959-967ICES 1995. Report of the Arctic Fisheries Working Group, Copenhagen August 23 – September 1, 1994. ICES C.M. 1995/Assess:3, 252 pp.

Hamre, J. and Hatlebakk, E., (1998). ’System Modell (Systmod) for the Norwegian Sea and the Barents Sea. In: T. Rødseth (Ed.). Models for multispecies management. Physica-Verlag. 1998. – p. 117-141.

Haug, T., Gjøsæter, H., Lindstrøm, U. and Nilssen, K.T., (1995). ‘Diet and food availability for northeast Atlantic minke whales (Balaenoptera acutorostrata), during the summer of 1992’, ICES J. of Mar. Sci. 52, 77-86.

Helland-Hansen, B. and Nansen, F., (1909). ’The Norwegian Sea’. FiskDir. Skr. Ser. HavUnders., 2: 1-360.

Humborstad, O.B., Løkkeborg, S., Hareide, N.R. and Furevik, D.M., (2003). Catches of Greenland halibut (*Reinhardtius hippoglossoides*) in deepwater ghostfishing gillnets on the Norwegian continental slope. Fisheries Research 64 (2-3): 163-170.

Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M., (2003). ‘The North Atlatic Oscillation; Climatic significance and environmental impact’, Geophysical monograph series, American Geophysical Union, Washington DC, 279 pp.

ICES, (1975). ‘Report of the North-East Arctic Fisheries Working group’. ICES C.M.1975/F:6, 14 pp.

ICES, (1995). ‘Report of the Arctic Fisheries Working Group’, Copenhagen August 23 – September 1, 1994. ICES C.M. 1995/Assess:3, 252 pp.

ICES, (1999). ‘Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP)’. Tromsø, Norway, September 29- October 2, 1998. ICES C.M. 1999/ACFM:7. 33 pp.

ICES, (2003). ‘Report of the Arctic Fisheries Working Group’, San Sebastian, Spain April 23 – May 2, 2003. ICES C.M. 2003/ACFM:22, 448 pp.

ICES, (2005). ‘Report of the Arctic Fisheries Working Group’, Murmansk, Russia, April 19-28, 2005. ICES C.M. 2005/ACFM:20, 564 pp.

ICES, (2006). 'Report of the Northern Pelagic and Blue Whiting Fisheries Working Group', Copenhagen August 25 – September 1, 2005. ICES C.M. 2006/ACFM:05, 241 pp.
ICES, (2006). Report of the Workshop on Simple Mixed Fisheries Management Models (WKMIXMAN), ICES Headquarters 9-13 January 2006. ICES C.M. 2006/ACFM:14, 47pp.
ICES, (2006). Report of the Arctic Fisheries Working Group, ICES Headquarters 19 - 28 April 2006. ICES C.M. 2006/ACFM:25, 594 pp.
Ingvaldsen, R.B., Asplin, L. and Loeng, H., (2004). 'Velocity field of the western entrance to the Barents Sea', J. Geophys. Res., 109, 1-12.
Ingvaldsen, R., Loeng, H. and Asplin, L., (2002). 'Variability in the Atlantic inflow to the Barents Sea based on a one-year time series from moored current meters'. Continentall Shelf research, 22 (3): 505-519.
Ingvaldsen, R.B., Loeng, H., Ottersen, G. and Ådlandsvik, B., (2003). 'Climate variability in the Barents Sea during the 20th century with focus on the 1990s', ICES Marine Science Symposia, 219, 160-168.
Jennings, S., (2004). 'The ecosystem approach to fisheries management: a significant step towards sustainable use of the marine environment? Perspectives on ecosystem-based approaches to the management of marine resources'. Marine Ecology Progress Series, 274: 269-303.
Jiang, W. and Jørgensen, T., (1996). 'The diet of haddock (Melanogrammus aeglefinus L.) in the Barents Sea during the period 1984-1991', ICES J. Mar. Sci., Academic Press Ltd.
Johannesen, E., Johansen, G.O., Bogstad, B., Mehl, S., Tjelmeland, S. and Dolgov, A., (2006). 'Cod Consume Capelin'. Working document #20 in: Report of the Arctic Fisheries Working Group, ICES Headquarters 19 - 28 April 2006. ICES C.M. 2006/ACFM:25, 594 pp.
Jørgensen, L.L., (2005). 'Impact Scenario for an Introduced Decapod on Arctic Epibenthic Communities', Biological Invasions 7, 949–957
Jørgensen, L.L. and Primicerio, R., (in press). 'Impact scenario for the invasive red king crab Paralithodes camtschaticus (Tilesius, 1815) (Reptantia, Lithodidae) on Norwegian, native, epibenthic prey', Special Issue on Crustacean Invaders for the journal Hydrobiologia.
Jørgensen, L.L., Manushin, I., Sundet, J.H. and Birkely, S.-R., (2004). 'The intentional introduction of the marine Red King Crab Paralithodes camtschaticus into the Southern Barents Sea', In: ICES (ed) Report of the Working Group on Introductions and Transfers of Marine Organisms (WGITMO). ICES Spec. Adv. Rep., Cesenatico, Italy, pp 124-137.
Korzhev, V.A. and Dolgov, A.V., (1999). 'Multispecies model MSVPA for commercial species in the Barents Sea'. Murmansk: PINRO press, 1999. 82 pp.
Kovalev, Y.A. and Bogstad, B., (2005). 'Evaluation of maximum long-term yield for Northeast Arctic cod', pp 138-157 in: Shibanov, V. (ed.). "Ecosystem Dynamics and Optimal Long-Term Harvest in the Barents Sea Fisheries". Proceedings of the 11th Russian-Norwegian Symposium, Murmansk, Russia, August 15 - 17, 2005. IMR/PINRO Joint Report Series No 2/2005, 331 pp.
Kutti, T., Høisæter, T., Rapp, H.T., Humborstad, O.B., Løkkeborg, S. and Nøttestad, L., (2005). 'Immediate effects of experimental otter trawling on a sub-arctic benthic assemblage inside Bear Island Fishery Protection Zone in the Barents Sea', Am. Fish. Soc. Symp.
Lindstrøm, U., Harbitz, A., Haug, T. and Nilssen, K., (1998). 'Do harp seals *Phoca groenlandica* exhibit particular prey preferences?', ICES J. Mar. Sci., 55, 941-953.

Lindstrøm, U., Haug, T. and Røttingen, I., (2002). 'Predation on herring, *Clupea harengus*, by minke whales, *Balaenoptera acutorostrata*, in the Barents Sea', ICES J. Mar. Sci., 59, 58-70.

Loeng, H., Blindheim, J., Ådlandsvik, B. and Ottersen, G., (1992). 'Climatic variability in the Norwegian and Barents Seas', ICES Mar. Sci. Symp., 195, 52-61.

Lukmanov, E.G., Baranenkova, A.S. and Klimenkov, A.I., (1975). 'Biology and fisheries of saithe in the Northern European seas', Murmansk, 64 pp. (in Russian)

Løkkeborg, S., (2003). 'Review and evaluation of three mitigation measures - bird-scaring line, underwater setting and line shooter - to reduce seabird bycatch in the North Atlantic longline fishery', Fish. Res., 60 (1), 11-16.

Løkkeborg, S., (2005). 'Impacts of trawling on benthic habitats and communities', FAO Fisheries Technical Paper. No. 472. Rome, FAO. 2005. 58p. (http://www.fao.org/docrep/008/y7135e/y7135e00.htm).

Marshall, C.T., Needle, C., Yaragina, N.A., Aijad, A. and Gusev, E.V., (2004). 'Deriving condition indices from standard fisheries databases and evaluating their sensitivity to variation in stored energy reserves', Can. J. Fish. Aquat. Sci., 61, 1900-1917.

Mauchline, J., (1998). ‚The biology of calanoid copepods'. Advances in Marin Biology 33, Academic Press, London. 710 pp.

Mauritzen, M., Skaug, H.J. and Øien, N., (in press). 'Line transects, environmental data and GIS: cetacean habitat and prey selection along the Barents Sea shelf edge', In: Lockyer, C. and Pike, D. (Eds.) North Atlantic Sighting Surveys. North Atlantic Marine Mammal Commision Scientific Publications, Tromsø.

Mehl, S. and Yaragina, N.A., (1992). 'Methods and results in the joint PINRO-IMR stomach sampling program', In: Bogstad, B. and Tjelmeland, S. (eds.) Interrelations between fish populations in the Barents Sea. Proceedings of the Fifth PINRO-IMR Symposium, Murmansk, August 12 – 16, 1991, 5-16.

Melle, W., Ellertsen, B. and Skjoldal, H.R., (2004). 'Zooplankton: The link to higher trophic levels', In: Skjoldal, H.R. (ed.) The Norwegian Sea Ecosystem. Tapir Academic Press, Trondheim.

Nakken, O. and Raknes, A., (1996). 'Corrections of indices of abundance of 0-group fish in the Barents Sea for varying capture efficiency', ICES CM 1996/G:12.

Michalsen, K. and Nedreaas, K.H., (1998). 'Food and feeding of Greenland halibut (Reinhardtius hippoglossoides, Walbaum) in the Barents Sea and East Greenland waters', Sarsia, Vol. 83, No. 5, 401-407.

Michalsen, K., Ottersen, G. and Nakken, O., (1998). 'Growth of North-east Arctic cod (Gadus morhua L.) in relation to ambient temperature'. ICES Journal of Marine Science, 55 (5): 863-877.

Mironova, N.V., (1956). 'Feeding and growth of gadoids juveniles in the coastal zone of Eastern Murman', Moscow - Leningrad, AN USSR Press, 99 pp. (in Russian)

Nedreaas, K., (1998). 'Abundance measurement of Saithe, Finnmark-Møre, autumn 1997'. Fisken og Havet, no. 6, 17 pp., 18. March 1998.

Nilssen, E.M. and Hopkins, C.C.E., (1992). 'Regional variability in fish - prawn communities and catches in the Barents Sea, and their relationship to the environment', ICES Mar. Sci. Symp., 195, 331-348.

Nilssen, K.T., Pedersen, O.-P., Folkow, L. and Haug, T., (2000). 'Food consumption estimates of Barents Sea harp seals', NAMMCO Scientific Publications 2, 9-27.

Nizovtsev, G.P., (1975). 'On the feeding of Greenland halibut Reinhardtius hippoglossoides (Walbaum) in the Barents Sea', Deponent of TSNIITEIRKH 8I25 №44, 41 pp. (in Russian)

Norderhaug, M., Bruun, E. and Møllen, G.U., (1977). 'Barentshavets sjøfuglressurser', Norsk Polarinstitutts Meddelelser 104, 119 pp.

Olsen, A., Johannessen, T. and Rey, F., (2003). 'On the nature of the factors that control spring bloom development at the entrance to the Barents Sea and their interannual variability', Sarsia, 88, 379-393.

Orlova, E.L., Oganin, I.A. and Terestchenko, E.S., (2001). 'On the causes of fluctuations of the polar cod importance in the North-East Arctic cod feeding'. Fisheries, № 1, 30-33. (in Russian)

Orvik, K.A. and Skagseth, O., (2003). 'The impact of the wind stress curl in the North Atlantic on the Atlantic inflow to the Norwegian Sea toward the Arctic'. Geophysical Research Letters, 30(17).

Ottersen, G., Alheit, J., Drinkwater, K., Friedland, K., Hagen E. and Stenseth, N.C., (2004). 'The response of fish to ocean climate variability'. pp 71-94. In: Stenseth, N.C., Ottersen, G., Hurrell, J. and Belgrano, A. (eds.) Marine Ecosystems and Climate Variation: North Atlantic. Oxford University Press, Oxford, UK.

Ottersen, G., Helle, K. and Bogstad, B., (2002). 'Do abiotic mechanisms determine interannual variability in length-at-age of juvenile Arcto-Norwegian cod?'. Can J Fish Aquat Sci 59:57-65.

Ottersen, G., Ådlandsvik, B. and Loeng, H., (2000). 'Predictability of Barents Sea temperature'. Fisheries Oceanography 9: 121-135.

Ozhigin, V.K., Drobysheva, S.S., Ushakov, N.G., Yaragina, N.A., Titov, O.V. and Karsakov, A.L., (2003). 'Interannual variability in the physical environment, zooplankton, capelin (*Mallotus villosus*) and North-East Arctic cod (*Gadus morhua*) in the Barents Sea'. ICES Mar. Sci. Symp., 219, 283-293.

Ponomarenko, I.Ya., (1973). 'The influence of feeding and temperature conditions on survival of the Barents Sea "bottom" juvenile cod'. Voprosy okeanografii severnogo promyslovogo basseina: Selected papers of PINRO. Murmansk, 1973. Vyp. 34, 210-222 (in Russian).

Ponomarenko, I.Ya., (1984). 'Survival of "bottom juvenile" cod in the Barents Sea and determining factors'. Cod reproduction and recruitment: Proceedings of the first Soviet-Norwegian symposium/VNIRO. – M., 1984, 301-315 (in Russian).

Ponomarenko, I.Ya. and Yaragina, N.A., (1990). 'Long-term dynamics of the Barents Sea cod feeding on capelin, euphausiids, shrimp and the annual consumption of these objects'. Feeding resources and interrelations of fishes in the North Atlantic: Selected papers of PINRO. Murmansk, 1990, 109-130 (in Russian).

Prozorkevich, D., (2001). 'Prediction of commercial fish recrutment based on 0-group survey data'. PINRO press, 2001.

Rey, F., (1981). 'The development of the spring phytoplankton outburst at selected sites off the Norwegian coast'. In: Sætre, R. and Mork, M. (eds.) The Norwegian Coastal Current. Bergen, University of Bergen, 649-680.

Rey, F., (1993). 'Planteplanktonet og dets primærproduksjon I det nordlige Barentshavet'. Fisken og Havet, 10, 39 pp.

Røttingen, I. and Tjelmeland, S., (2003). 'Evaluation of the absolute levels of acoustic estimates of the 1983 year class of Norwegian spring spawning herring'. ICES J. Mar. Sci., 60, 480-485.

Sakshaug, E. and Skjoldal, H.R., (1989). 'Life at the ice edge'. Ambio, Vol. 18, no. 1, 60-67, Stockholm

Schweder, T., Skaug, H.J., Dimakos, X.K., Langaas, M. and Øien, N., (1997). 'Abundance of northeastern Atlantic minke whales, estimates for 1989 and 1995'. Rep. Int. Whal. Comm., 47, 453-483.

Shvagzhdis, A.P., (1990). 'Feeding peculiarities of Greenland halibut from Norwegian-Barents Sea stock in 1980-1989'. ICES CM 1990 G:12, 18 pp.
Sirenko, B.I., (2001). 'List of species of free-living invertebrates of Eurasian Arctic Seas and adjacent deep waters'. Russian Academy of Sciences, St. Petersburg
Skaug, H.J., Øien, N., Bøthun, G. and Schweder, T., (2002). 'Abundance of northeastern Atlantic minke whales for the survey period 1996-2001'. Rep. Int. Whal. Comm., SC/54/RMP5.
Skaug, H.J., Øien, N., Schweder, T. and Bøthun, G., (2004). 'Abundance of Minke Whales (*Balaenoptera acutorostrata*) in the Northeast Atlantic: Variability in Time and Space'. Can. J. Fish. Aq. Sci., 61, 870-886.
Skjoldal, H.R., and Rey, F., (1989). 'Pelagic production and variability of the Barents Sea ecosystem'. In: Biomass Yields and Geography of Large Marine Ecosystems. Sherman, K. and Alexander, L.M. (eds.) American Association for the Advancement of Science, pp. 241-286.
Sund, O., (1938). 'Biological and oceanographic investigations. 8. Cod stocks in 1938. Fish movements and replacements'. Årsberetning Norg. Fisk., 2: 87-102.
Skogen, M.D., Budgell, W.P. and Rey, F., (in prep). 'Interannual variability of the Nordic Seas primary production'.
Stiansen, J.E., Bogstad, B., Dalpadado, P.,Gjøsæter, H., Hauge, K.H., Ingvaldsen, R., Loeng, H., Mauritzen, M., Mehl, S. Ottersen, G. and Stenevik, E.K., (2005). 'IMR status report on the Barents Sea Ecosystem, 2005-2005'. Working document #1 in: Report of the Arctic Fisheries Working Group', Murmansk, Russia, April 19-28, 2005. ICES C.M. 2005/ACFM:20, 564 pp.
Sundby, S., (1991). 'Factors affecting the vertical distribution of eggs'. ICES Mar. Sci. Symp., 1991, Vol. 192, 33-38.
Sundby, S., (1993). 'Wind climate and foraging of larval and juvenile Arcto-Norwegian cod'. Can. J. Fish. Aquat. Sci., 1993, Vol. 50.
Sundby, S., (2000). 'Recruitment of Atlantic cod stocks in relation to temperature and advection of copepod populations'. Sarsia, 2000, Vol. 85, No. 4, 277-298.
Titov, O., Pedchenko, A. and Karsakov, A., (2005). 'Assessment of Northeast Arctic cod and capelin recruitment from data on ecological situation in the Barents Sea I 2004-2005'. Working document #16 in: Report of the Arctic Fisheries Working Group', Murmansk, Russia, April 19-28, 2005. ICES C.M. 2005/ACFM:20, 564 pp.
Tjelmeland, S. and Bogstad, B., (1998). 'MULTSPEC – A review of a multispecies modelling project for the Barents Sea'. Fish. Res., 37, 127-142.
Tjelmeland, S. and Lindstrøm, U., (2005). 'An ecosystem element added to the assessment of Norwegian spring spawning herring: implementing predation by minke whales'. ICES J. Mar. Sci., 62(2), 285-294.
Tseeb, R.Ya., (1964). 'feeding and feeding adaptations of haddock'. Moscow-Leningrad, Nauka Publishing. 134 pp. (in Russian)
Ushakov, N.G. and Shamray, E.A., (1995). 'The effect of different factors upon the Barents Sea capelin year classes'. Pp. 75-84 in Hylen, A. (ed): Precision and relevance of prerecruit studies for fishery management related to fish stocks in the Barents Sea and adjacent waters. Proceedings of the sixth IMR-PINRO symposium, Bergen, June 14 – 17, 1994. Institute of Marine Research, Bergen, Norway.
Von Quillfeldt, C. and Dommasnes, A., (sci. eds.) (2005). 'Report of the working group on fish stocks and fisheries (including production and energy flows). The Scientific Basis for Environmental Quality Objectives (EcoQOs) for the Barents Sea Ecosystem'. Norway, 2005.

Wassmann, P., Egge, J.K., Reigstad, M. and Aksnes, D.L., (1997). 'Influence of dissolved silicate on vertical flux of particulate biogenic matter'. Marine Pollution Bulletin, Vol. 33, 10-21

Yaragina, N.A. and Marshall, C.T., (2000). 'Trophic influences on interannual and seasonal variation in the liver condition index of Northeast Arctic cod (*Gadus morhua*)'. ICES J. Mar. Sci., 2000, 42-55.

Zatsepin, V.I., (1939). 'Feeding of haddock in the Murman coast in relation to bottom fauna'. Trudy PINRO, Vol. 3, 39-98. (in Russian)

Zenkevitch, L.A., (1963). 'Biology of the Seas of the USSR'. London, Allen and Unwin, 931 pp.

Øien, N., (1996). 'Lagenorhynchus species in Norwegian waters as revealed from incidental observations and recent sighting surveys'. Paper SC/48/SM15 to the IWC Scientific Committee, Aberdeen.

Øien, N., (2003). 'Distribution and abundance of large whales in the northeast Atlantic, 1995'. Working Paper NAMMCO SC/11/MF/10 to the Working Group on Minke and Fin Whales, Copenhagen, Denmark, 20-22.

Ådlandsvik, B. and Loeng, H., (1991). 'A study of the climatic system in the Barents Sea'. Polar Res., 10, 45-49.

Web addresses:

Climatic and monthly sea level pressure and wind fields are available at web: http://www.cdc.noaa.gov/cgi-bin/composites/printpage.pl/.

Time series of monthly mean air temperatures from various stations can be found at web: http://data.giss.nasa.gov/gistemp/station_data/.

Benthic communities at the Barents Sea ice edge in a changing climate (BASICC)
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