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JOINT PINRO/IMR REPORT ON THE STATE OF THE BARENTS SEA ECOSYSTEM IN 2007 WITH EXPECTED SITUATION AND CONSIDERATIONS FOR MANAGEMENT

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Joint PINRO/IMR Report on the State of the Barents Sea Ecosystem in 2007, with Expected Situation and Considerations for Management

Issue No 3

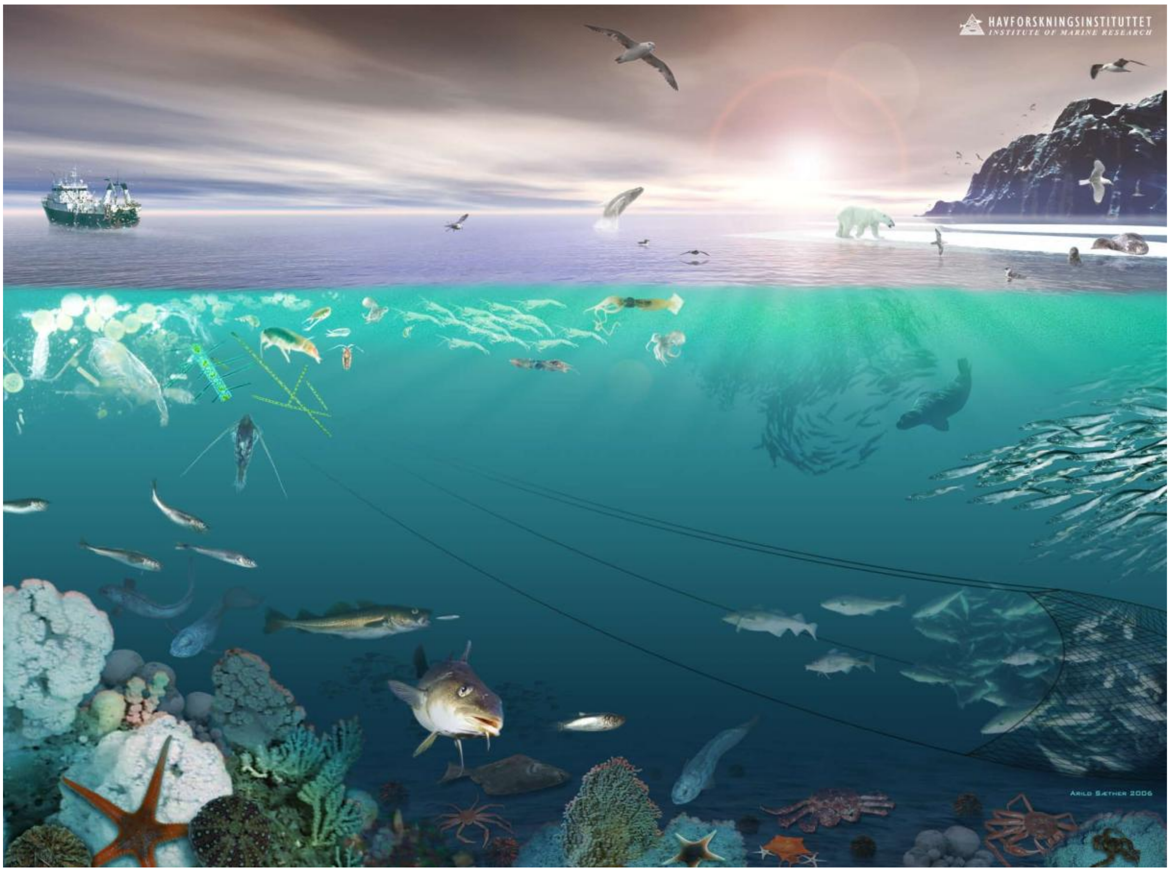

Figure 1.1. Illustration of the rich marine life and interactions in the Barents Sea.

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Contents

1 Introduction

By J.E. Stiansen (IMR), A. A. Filin (PINRO) and M.M. McBride (IMR)

The Barents Sea is strongly influenced by human activity; historically involving the fishing and hunting of marine mammals. More recently, human activities also involve transportation of goods, oil and gas, tourism and aquaculture. Large-scale harvesting in the Barents Sea strongly impacts not only the status of commercially important species, but also the ecosystem as a whole.

The Barents Sea ecosystem is also strongly influenced by climatic conditions. Year-to-year variations in strength of Atlantic water inflow lead to adjustments in the ecosystem that influence fish production. In recent years interest has increased to evaluatelikely response of the ecosystem to future climate changes. Anthropogenic warming is projected to lead to increased air and sea temperatures globally, with the highest increases in air temperature in Arctic and Subarctic regions. Climatic conditions effect primary production and feeding conditions for fish, as well as survival of their progeny. Another key factor that influences the abundance and population dynamics of commercially important species is inter-specific trophic relations.

The ecosystem approach to management (EAM) of marine resources is now generally recognized as the future direction. EAM has been variously defined, but emphasizes management that maintains health of the ecosystem through judicious use of ecosystem services for the benefit of current and future generations (Jennings, 2004). EAM must be based on scientific understanding of ecosystem structure and function. To gain this knowledge, it is necessary to monitor the ecosystem, and develop indicators that describe health of the ecosystem taking into account both natural variations and anthropogenic impacts. Such indicators should be easily available, and frequently updated to evaluate current ecosystem status; they should also be helpful to make forecasts for operational use.

EAM is not a new concept: in 1975, trophic relationship between cod, haddock and capelin were discussed in the Arctic Fisheries Working Group (AFWG) Assessment Report (ICES/AFWG, 1975). Efforts to identify key ecosystem information to describe fish stocks, and use it to assess fish stocks and forecast future conditions, have progressed in recent years. Information gathered in this report to describe the Barents Sea ecosystem will give better understanding of this complex and dynamic system, and will facilitate EAM in the Barents Sea and associated regions.

At the 2006 annual meeting between IMR and PINRO scientists, it was decided to begin production of this annual joint status report on the Barents Sea ecosystem. Information from this report will be used by the ICES Arctic Fisheries Working Group (AFWG) to include ecosystem consideration in advice provided for fisheries management. The scope of this report is much wider, however. Its target audience is the scientific community; but, it should also prove useful to managers, non-governmental organisations, and private individuals who want to understand the scientific basis for an EAM.

The report is divided into 7 main chapters. Chapter 2 provides a general description of the Barents Sea ecosystem, and identifies critical linkages within. Chapter 3 gives an overview of ecosystem surveillance. Chapter 4 describes the present conditions, often from an historical perspective; emphasis is placed on situations that deviate from the norm. When possible, forecasts are made on what can be expected in the near future. Chapter 5 describes types of analysis and models that use the ecosystem data, and how this information can be used to support EAM decisions. Chapter 6 describes impacts on the ecosystem from fishery activities. Issues with pollution are described in Chapter 7. Chapter 8 identifies and discusses the hazards and risks associated with sudden catastrophic events.

The current volume is the third in this annual series of reports. It has been distributed to scientists, managers, environmental and fishery organisations, and politicians; it can also be accessed at: http://www.imr.no/english/imr_publications/imr_pinro.

Next year's issue will be a little different from the previous issues. Upon request from the Norwegian-Russian Environmental Committee, and approved by the Joint Norwegian-Russian Fisheries Commission, the report will include contributions from 16 Norwegian and 6 Russian institutions; the name will be changed to "*Joint Norwegian-Russian Environmental Status Report on the Barents Sea Ecosystem for 2008*". The new report, however, will continue as part of the present series. The content will be extended with more topics (e.g. infectious organisms), and existing chapters will have cover a broader scientific basis to present a more holistic overview of the ecosystem.

2 General description of the ecosystem

2.1 Overview of the ecosystem

By Å. Høines (IMR), A. Filin (PINRO), V.K. Ozhigin (PINRO) and J.E. Stiansen (IMR)

The Barents Sea is a sub-Arcticecosystem located between 70 and 80ºN. Its shelf area is approximately 1.4 million km^{2}. It connects with the Norwegian Sea to the west and the Arctic Ocean to the north. The average depth is 230 m; the maximum depth is approximately 500 m at the western entrance. There are several bank areas, with depths ranging from 50-200 m. The general pattern of circulation (Figure 2.1) is strongly influenced by this topography, and is characterised by inflow of relatively warm Atlantic water, and coastal water from the west. This current divides into two branches: 1) a southern branchthat flows parallel to the coast and eastwards towards Novaya Zemlya; and 2) a northern branch that flows into the Hopen Trench. The Coastal Water has more fresh-water runoff and a lower salinity than the Atlantic water; it also has a stronger seasonal temperature signal. In the northern region of the Barents Sea, fresh and cold Arctic waters flow from northeast to southwest. Atlantic and Arctic water masses are separated by the Polar Front, which is characterised by strong gradients in both temperature and salinity. There is large interannual variability in ocean climate related to variable strength of the Atlantic water inflow, and exchange of cold Arctic water. Thus, seasonal variations in hydrographic conditions can be quite large.

The Barents Sea is a spring bloom system; during winter, primary production is close to zero. Timing of the phytoplankton bloom varies throughout the Barents Sea; there also can be high interannual variability. The spring bloom starts in the south-western areas and spreads north and east with the retracting ice as it melts. In early spring, the water becomes mixed from surface to bottom; despite adequate nutrient and light conditions for production, however, the main bloom does not occur until the water becomes stratified. Fish and mammals have similarly directed seasonal feeding migrations so that the stocks in the area will have their most northern and eastern distribution in August-September and be concentrated in the southern and south-western areas in February-March.

Stratification of water masses in different areas of the Barents Sea may occur in several different ways; 1) through fresh surface water from melting ice along the marginal ice zone; 2) through solar heating of surface layers in Atlantic water masses; or 3) through lateral dispersion of waters in the southern coastal region (Rey 1981). As in other areas, diatoms are the dominant algal group in the Barents Sea (Rey 1993); they particularly dominate the first spring bloom, when the most abundant species is *Chaetoceros socialis*. Concentrations of diatoms can reach up to several million cells per litre. They require silicate and when this is consumed, other algal groups such as flagellates take over. An important flagellate species in the Barents Sea is *Phaeocystis pouchetii*; other species may predominate the spring bloom in different years, however.

Zooplankton biomass in the Barents Sea can vary significantly between years. Crustaceans are an important group of zooplankton; among crustaceans, copepods of the genus Calanus play a key role in this ecosystem. Calanus finmarchicus, is most abundant in Atlantic waters, and forms the largest component of total zooplankton biomass. In Arctic waters of the Barents Sea C. glacialis is most abundant and forms the largest component of zooplankton biomass.

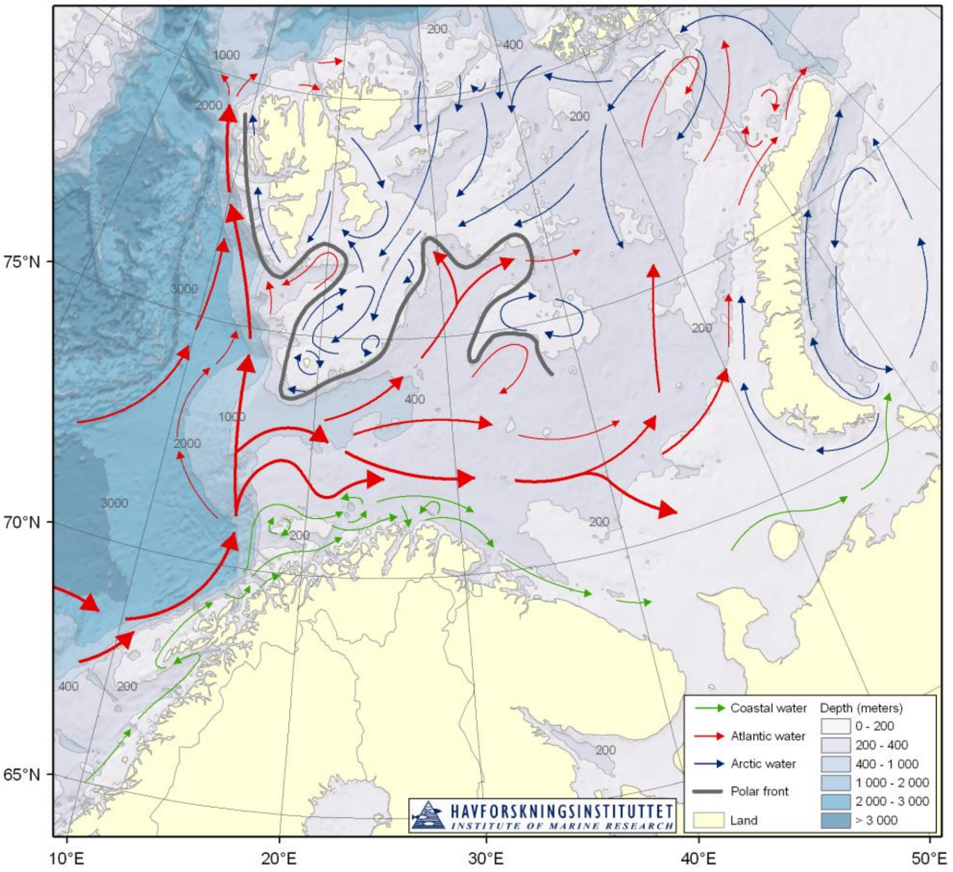

Figure 2.1. Main features of circulation and bathymetry in the Barents Sea.

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

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

“Gelatinous zooplankton” is a term often used by non-specialists in reference to classes of organism that are jelly-like in appearance; the term "jellyfish" is commonly used in reference to marine invertebrates belonging to the class Scyphozoa, phylum Cnidaria. Neither of these terms implies any systematic relationship to vertebrate fish. The term "jellyfish" is also often used in reference to relatives of true scyphozoans, particularly the Hydrozoa and the Cubozoa. There is no time series of data available to characterize populations of these organisms in the Barents Sea. Both comb-jellies (Ctenophora) and "true" jellyfish are predators; they competewith plankton-eating fish, as copepods often are significant prey items for all. Together with increased temperatures, and changes in other components of the Barents Sea ecosystem, research interest has increased to understand how these changes effect abundance and distributionof gelatinous zooplankton.

More than 3,050 species of invertebrate benthic fauna inhabit the Barents Sea (Sirenko 2001). Most of the area is covered by fine-grained sediment; a more coarsesedimentis found on the relatively shallow shelf banks (<100m), and in the sub-littoral zone around islands (Zenkevitch, 1963). Stones and boulders are locally abundant. Southwestern regions of the Barents Sea are influenced by Atlantic waters which bring diverse warm-water fauna; the number of cold-water species increases to the east and north. Benthic communities depend on inputs of organic matter from the water column, hence, characteristics of the overlying pelagic ecosystem largely determine variation in species composition of the benthos. Three species of bottom invertebrates – Northern shrimp (*Pandalus borealis*), Iceland scallop (*Chlamys islandica*), and red king crab (*Paralithodes camchaticus*) — are of economic importance. The red king crab was introduced into the Barents Sea in the 1960s. Presently it’s the largest predatory crustacean in the area. Shrimp are an important prey itemfor cod, and play an important role linking benthic and pelagic components of the food web in the Barents Sea ecosystem. In later years the snowcrab (*Chionoecetes opilio*), an invasive species, has increased in abundance.

The Barents Sea is a relatively simple ecosystem, with few fish species of potentially high abundance. Commercially important fish species include: Northeast Arctic cod; Northeast Arctic haddock; Barents Sea capelin; polar cod; and immature Norwegian spring-spawning herring. In years, increased numbers of blue whiting have migrated into the Barents Sea. Species distribution largely depends on positioning of the Polar Front. Variation in recruitment of species, including cod and herring, has been linked to changes in influx of Atlantic waters.

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

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

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

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

2.2 Geological and geographical description

By D. Howel (IMR)l, A. Filin (PINRO) and J.E. Stiansen (IMR)

The Barents Sea lies over the continental shelf surrounding the Arctic Ocean; it connects with the Norwegian Sea to the west and the Arctic Ocean to the north with the Norwegian Sea to the west and the Arctic Ocean to the north. Its contoursare delineated by the continental slope between Norway and Spitsbergen to the west, the top of the continental slope towards the Arctic Ocean to the north, Novaya Zemlya archipelago to the east, and the coasts of both Norway and Russia to the south (see Figure 2.1). It covers an area of approximaely 1.4 million km^2, has an average depth of 230 m, and a maximum depth of about 500m at the western end of Bear Island Trough (Figure 2.1). Its topography is characterized by relatively deep troughs and basins (300m – 500m deep), separated by shallow bank areas, with depths ranging from 100-200 m. The three largest banks are Central Bank, Great Bank and Spitsbergen Bank. Several troughs over 300m deep run from central Barents Sea to the northern (e.g. Franz Victoria Trough) and western (e.g. Bear Island Trough) continental shelf break. These troughs allow influx of Atlantic waters to the central Barents Sea.

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

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

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

2.3 Climate

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

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 environments in turn cause biological responses such as timing of spring phytoplankton bloom, zooplankton production, patterns of fish egg and larval 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 atmospheric pattern of seasonal and long-term variability in the North Atlantic (Figure 2.2). However, climatic conditions of the Barents Sea are determined by both Atlantic and Arctic climatic systems; the winter NAO index explains only about 15-20% (R^2=0.14-0.22) of interannual variability in air and sea temperature in the southern Barents Sea (Ozhigin *et al.*, 2003).

During cold seasons, a typical feature of atmospheric pressure is a low-pressure trough stretching from Iceland to the central Barents Sea. Pressure lows frequently travel along it bringing warm air from the Atlantic towards Novaya Zemlya archipelago (Figure 2.3). The southern Barents Sea is usually dominated by southwesterly winds, which contribute to increased advection of warm Atlantic water into the area. In the northern part of the sea, cold northeasternly winds predominate.

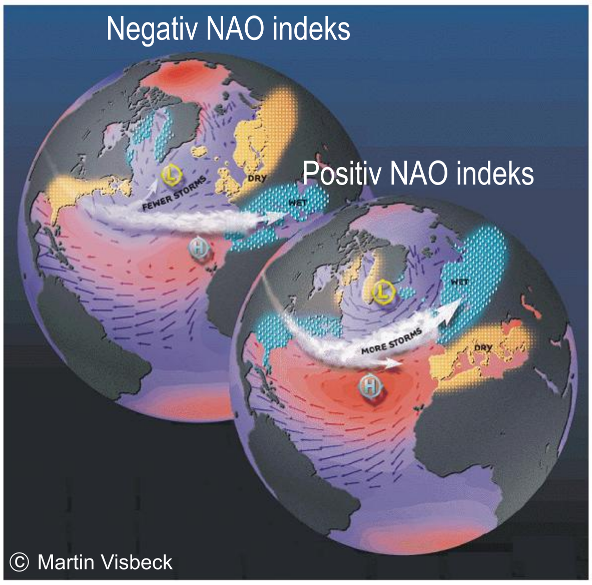

Figure 2.2. A positive NAO phase (bottom right globe) is characterized by a marked difference in air pressure between the low-pressure centre near Island and the high-pressure centre further south in the North Atlantic. In a positive NAO phase the dominating winds will be stronger than average and have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

During summer, contrasts in sea-level pressure are pronounced over the northeast Atlantic (Figure 2.3). In both Norwegian and Barents Seas, horizontal gradients of pressure are relatively small; as a result, light winds of different directions blow over the Barents Sea. In some years, cold northerly and northeasterly winds prevail — even in the southern part of the sea — during May-August.

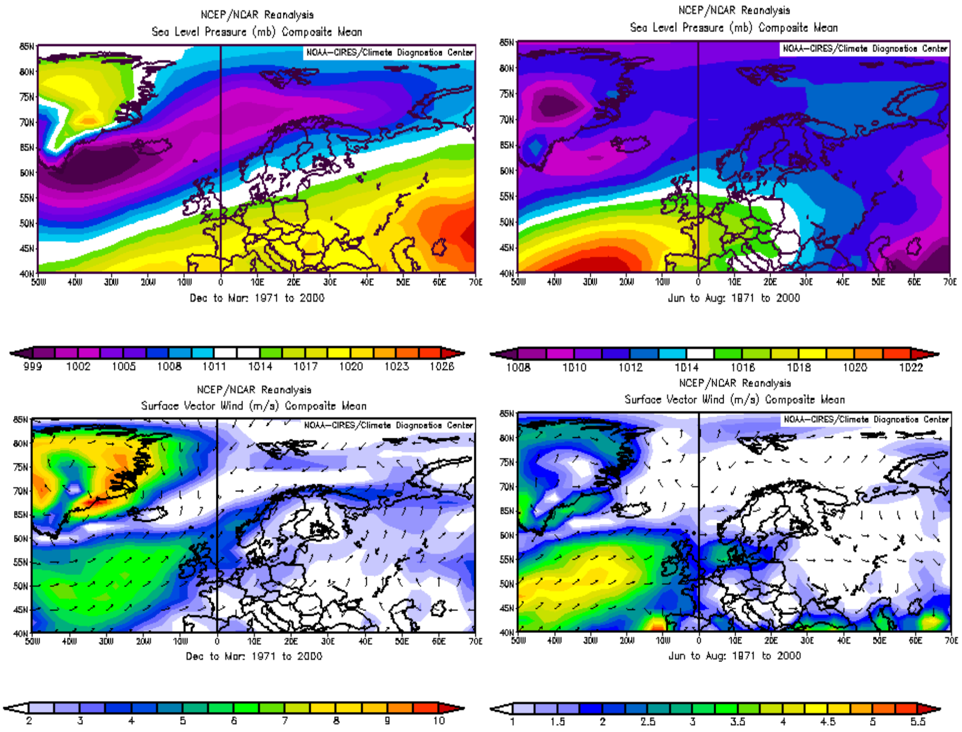

Figure 2.3. Long-term mean (1971-2000) sea level pressure (top) and wind vectors (bottom)) during December-March (left plates) and June-August (right plates). Data source for sea level pressure fields and wind vectors:: **http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl**.

Long-term seasonal mean sea-level pressure patterns greatly influence the spatial variation of air temperature in the Barents Sea. Figure 2.4 shows the climatic seasonal cycle of air temperature at different stations around the Barents Sea: Svalbard Airport (78.2°N, 15.5°E); Bear Island (74.5°N, 19.0°E); Murmansk (69.0°N, 33.0°E); Malye Karmakuly (72.4°N, 52.7°E); and Heiss Island (Franz Josef Land Archipelago) (80.6°N, 58.0°E). The long-term mean air temperature over the Barents Sea ranges from -7 °C in the south to -25 °C in the north during January, and from 12 °C to 1 °C in corresponding regions of the sea during July (Figure 2.4).

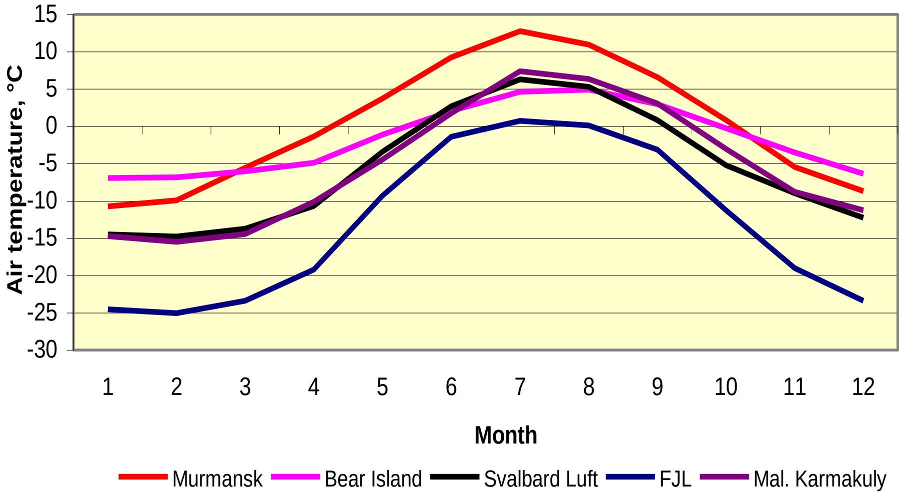

Figure 2.4. Climatic seasonal cycles of air temperature a: Svalbard Airport; Bear Island; Murmansk; Malye Karmakuly (southern Novaya Zemlya archipelago); and Franz Josef Land (GMO Im. E.T.). Data source: **http://data.giss.nasa.gov/gistemp/station_data/**.

2.3.2 Hydrographical conditions

2.3.2.1 General circulation

The Norwegian Atlantic Current carries warm and salty Atlantic water northwards along the Norwegian continental shelf break outside the Norwegian Coastal Current (Figure 2.1). When entering the Barents Sea it splits into two main branches. The first branch flows northeast along the Hopen Trench. The second branch flows eastward parallel to the coastal current towards Novaya Zemlya archipelago; this branch is called the 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 local wind conditions in the Barents Sea. Smaller Atlantic water currents also enter the Barents Sea from the north-west region; they generally branch into subsurface flows, and do not extend very far south, but may have substantial impact on climate conditions in the northwestern Barents Sea.

The Norwegian Coastal Current flows close to shore, and eastward into the Barents Sea. It carries relatively fresh water from the North Sea, and the Norwegian river system. During winter this current is deep and narrow, during summer it is wide and shallow. Its temperature has a strong seasonal signal. Cold fresh Arctic water arrives mainly from the Arctic Ocean; it enters the Barents Sea between Nordaustlandet and Franz Josef Land, and between Franz Josef Land and Novaya Zemlya archipelago. The latter branch flows westward across the northern Barents Sea, and along the eastern slope of Spitsbergen Bank where it joins the East Spitsbergen Current. These two currents continue as the Bear Island Current, following the topography around Spitsbergen Bank into Storfjord Trench, before it rounds the southern tip of West Spitsbergen through a narrow zone between land and Atlantic Water. Atlantic and Arctic water masses are separated by the Polar Front, which is characterised by strong temperature and salinity gradients. In western Barents Sea the front position is stable; in the eastern Barents Sea the front position varies seasonally and inter-annually.

2.3.2.2 Water masses and stratification

Atlantic Water is here defined as having salinity >35.0 and temperatures >3°C. Between Norway and Bear Island, the temperature of Atlantic Water varies seasonally and inter-annually from 3.5-7.5 °C; as a rule, both temperature and salinity decrease in northward and eastward directions (Figure 2.5). For this reason, water with salinity as low as 34.95 is commonly classified as water of Atlantic origin. In the southwestern Barents Sea, Atlantic water is normally predominant. Interannual temperature variation in the Barents Sea is illustrated in Figure 2.6, which presents annual temperature observations during the last 100 years for the Kola region (Bochkov, 1982, 2005) in the southern Barents Sea.

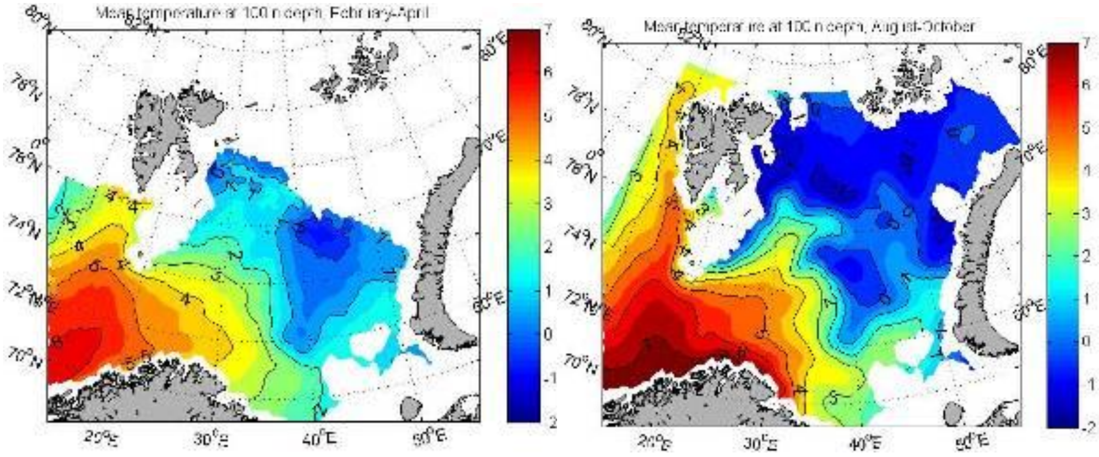

Figure 2.5. Average temperatures in the Barents Sea at 100 m. Based on observations during February-April (left plates) and August-October (right plates) for the period 1977-2007. During any specific year the Polar Front is quite sharp; this is not evident in the figure due to winter ice cover (that limits collection of data in northern areas) and interpolation effects.

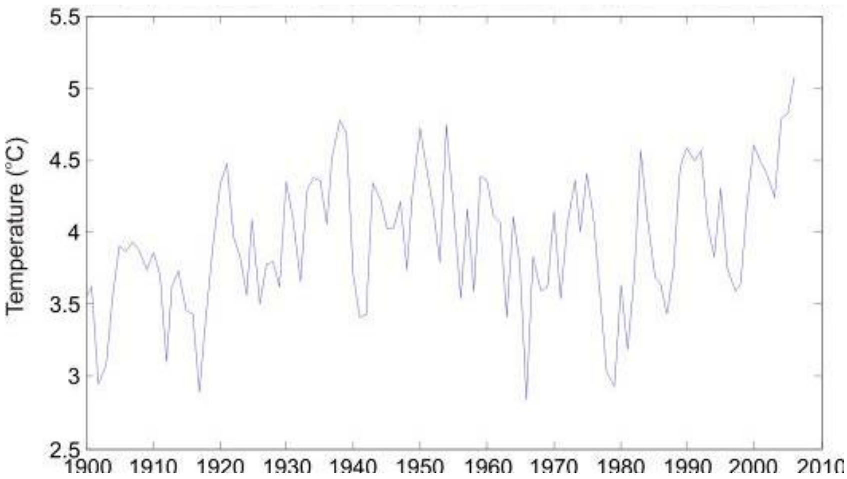

Figure 2.6. Average annual temperature between 0 and 200 m depth in the Kola region, stations 3-7 (Bochkov, 1982, 2005; www.pinro.ru).

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

The seasonal ocean temperature signal is strong, and lags behind air temperatures by 2-3 months (Figure 2.7). Maximum values are reached during September-October and minimum values during March-April.

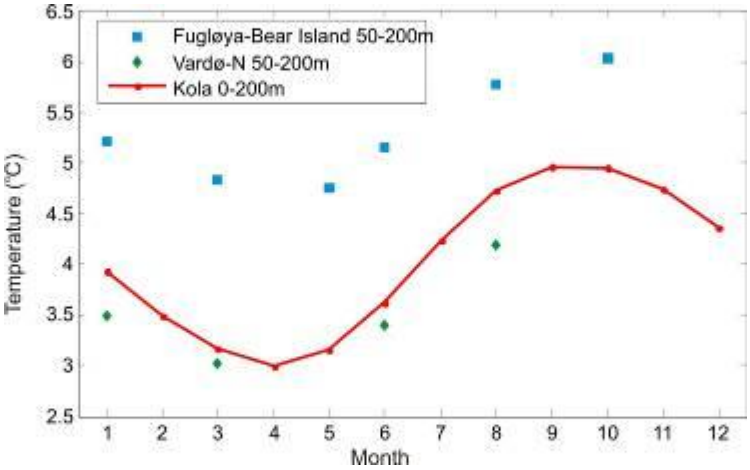

Figure 2.7. Climatic seasonal cycle in the southern Barents Sea. For Fulgøya-Bear Island and Vardø-N the ocean temperatures are between 50 and 200 m, for Kola temperatures are between 0 and 200 m.

Temperature in the upper 150 m layer of the water column reaches a seasonal minimum during April in the Kola region; this minimum occurs a bit later in deeper layers. The corresponding time delay — to reach a seasonal maximum temperature in deeper layers — is longer. In the upper 20 m layer of the water column, the seasonal maximum takesk place in August; the timing is then gradually delayed with increasing depth. As result, the time of temperature maximum near-bottom is between October and January (Figure 2.8).). This phenomenon was first noted by N.M.Knipovich (1906), and later described by many researchers (Sarynina, 1980; Tereshchenko, Bochkov, 1994; Tereshchenko, 1997, 2000; Boitsov, 2006).

Seasonal variation of salinity in the Kola region differs from that of temperature. Salinity variation in the upper 50 m layer of the water column has a minimum during August-September and a maximum during January-April. Northern stations of this region are an exception; there the seasonal maximums at depths extending down to 50 m occur during December. The seasonal signal at lower depths and/or near-bottom layers has not been determined; long-term data indicate that at such depths salinity stays constant year round (amplitude of the change is less than 0.05) (Figure 2.8) (Karsakov, 2007).

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

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

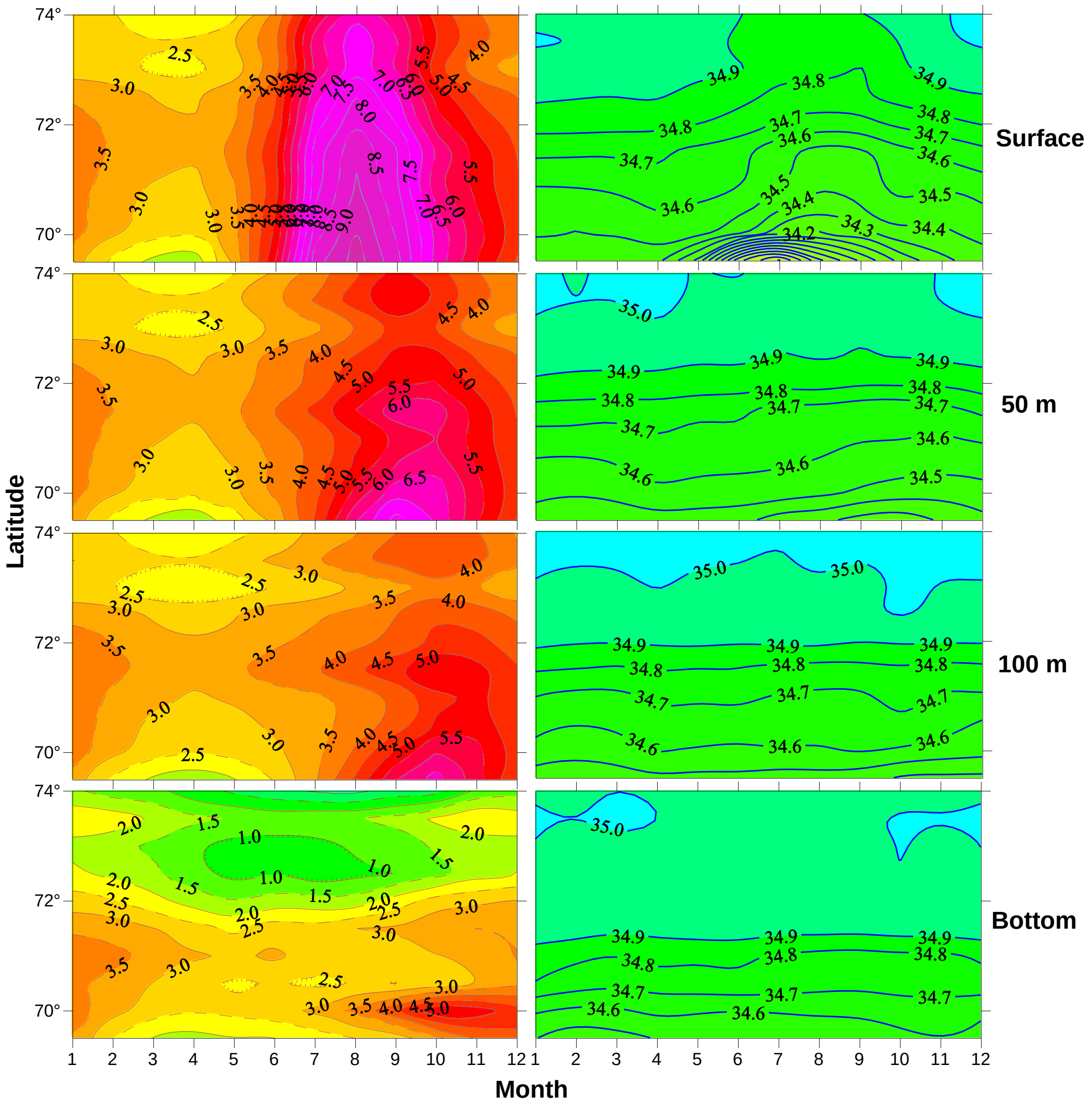

Figure 2.8. Seasonal variation of long-term mean temperature (left panels) and salinity (right panels) at sea surface, 50 m, 100 m,s and near-bottom depths in the Kola region.

2.3.2.3 Currents and transports

Observed current in the Fugløya- Bear Island region is predominantly barotropic, and reveals large fluctuations in both current speed and lateral structure (Ingvaldsen et al., 2002, 2004). Inflow of Atlantic water may come in one wide core or be split into several cores; between the cores, however, both inflow and outflow are weaker. In northern regions of the section, observed outflow has been more dynamic; the area involved may be much wider than earlier observed — stretching south to 72°N. This phenomenon is not necessarily short-term, and could take place over a month-long period. Patterns of outflow are most likely relatede to horizontal pressure gradients caused by: changes in sea level (between the Barents Sea and the Arctic Ocean or between the Barents Sea and the Norwegian Sea); water accumulation; or changes in atmospheric pressure.

There is apparent seasonality in structure of the current. During winter, frequent atmospheric lows, likely in combination with weak stratification, intensify the currents structuring of strong lateral velocity-gradients and a distinct, surface-intensified, relatively high-velocity core of inflow. During summer, weaker winds and stronger stratification create a wider area of inflow, while horizontal shear and velocities are lower. During summer, inflow is only to the upper 200 m in areas where Bear Island Trough is deepest.

Volume transport across the Barents Sea varies with season due to close coupling with regional atmospheric pressure. Numerical models forced with wind predict that southwest wind, which is predominant during winter, accelerates flow of Atlantic Water into the Barents Sea; whereas, weaker and more fluctuating northeast wind, common during summer, slows transport. The same conclusion is reached using current measurements in the exit area of northeast Barents Sea. Since 1997, monitoring transport of Atlantic Water into the Barents Sea indicates highly variable net transport that averages 1.7 Sv (Sv = 10^6 m^3 s^{-1}). The average transport of Atlantic Water into the Barents Sea during 1997-2007 is 2.2 Sv during winter and 1.8 Sv during summer. During years in which the Barents Sea changes from cold to warm marine climate, the seasonal cycle can be inverted. Moreover, an annual event of northerly wind causes a pronounced spring minimum inflow to the western Barents Sea; at times even an outward flow.

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

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

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

Monthly wind-driven and total volume fluxes through sections crossing the main currents of the Barents Sea were calculated with a numerical model for 1971-2000. Seasonal variations in the wind-driven and total fluxes are shown in Figure 2.9 and Figure 2.10, respectively.

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

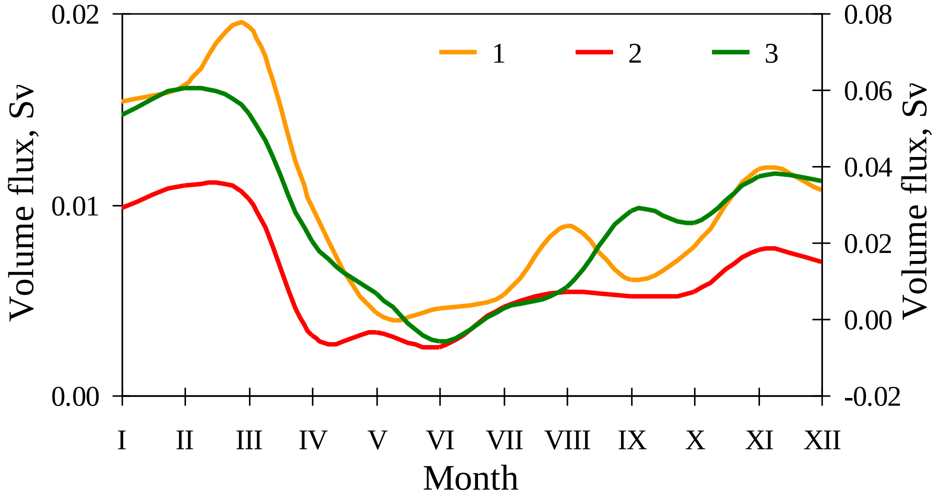

Figure 2.9. Seasonal variations in wind-driven flux throughe sections crossing West Spitsbergen Current (1), North Cape Current (2, right axes) and Murman Current (3, right axes).

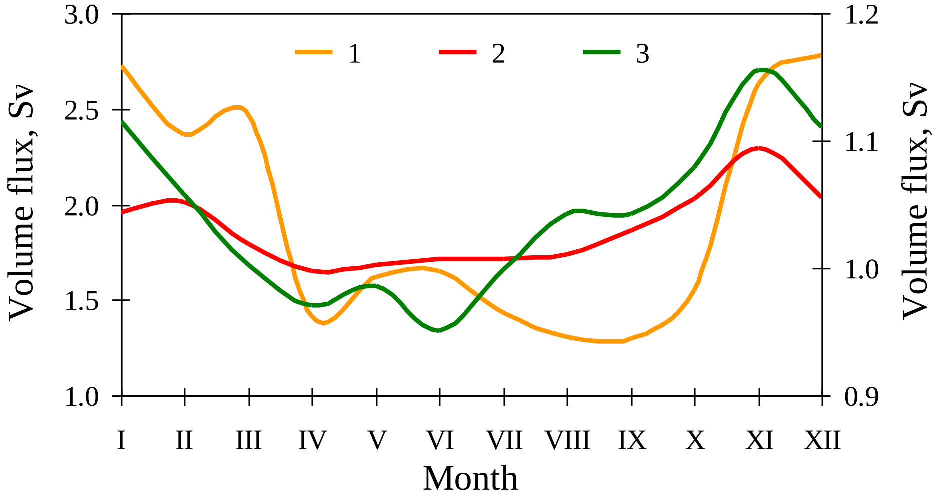

Figure 2.10. Sseasonal variations in total flux through sections crossing Spitsbergen Current (1), North Cape Current (2) and Murman Current (3, right axes).

2.3.2.4 Ice conditions

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

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

During winter, sea ice spreads from north to south and from east to west. This process lasts through the end of April. Even during May-June, the ice edge is located along the western coast of Novaya Zemlya archipelago. Warm waters of the Novaya Zemlya Current enter the northeastern extent of Barents Sea, and form a hollow in the ice edge in the direction of inflow. Through October, this ice edge may continue to retreat northward and the eastward (Zubakin, 1987) (Figure 2.11).

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

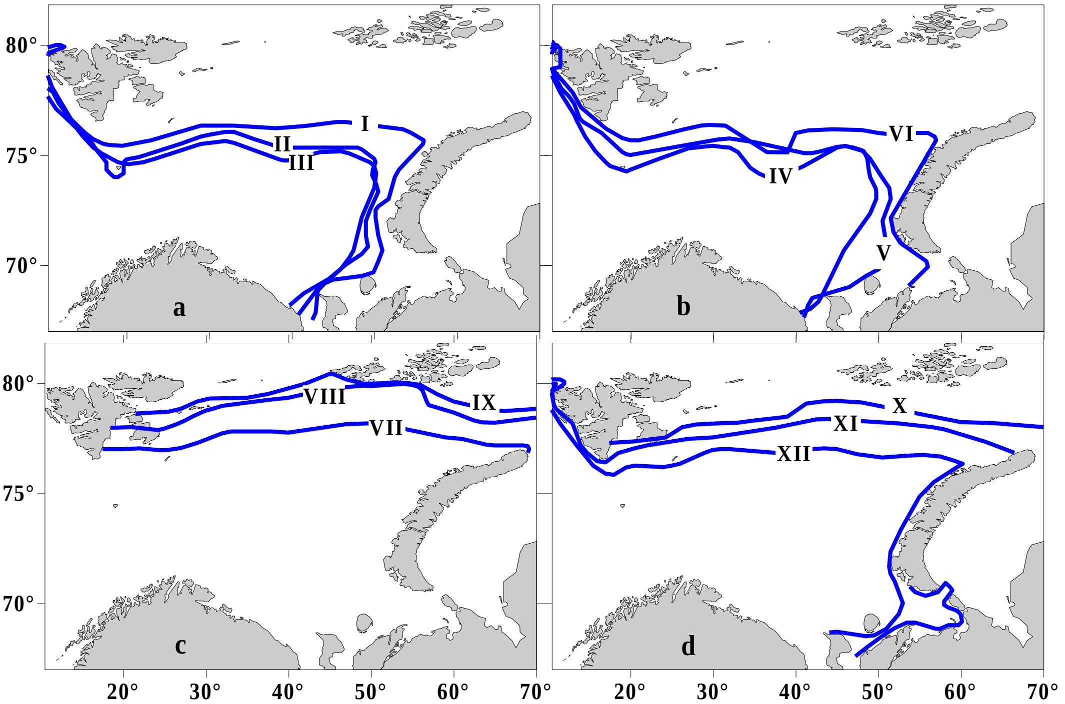

Figure 2.11. Long-term mean position of the ice edge in the Barents Sea during first (a), second (b), third (c) and fourth (d) quarters.

2.4 Species communities

2.4.1 Phytoplankton

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

The Barents Sea is a spring bloom system. Timing and development of the phytoplankton bloom shows high interannual variability throughout; particularly in regions where there is interannual variability in sea ice cover — the melting of which may cause stratification to appear earlier than if no ice were present (Olsen et al., 2003). During winter primary production is low and chlorophyll concentrations are close to zero; the water becomes mixed and nutrients are transported to the surface, so primary production is mainly limited by light. By early spring, the water is still mixed; there are adequate levels of nutrients, and enough light penetration for primary production. The main bloom does not appear, however, before the water becomes stratified. Stratification of water masses in different parts of the Barents Sea occurs in different ways. Along the marginal ice zone, increased sun radiation during spring melts the sea ice; a thin upper layer of relatively fresh melt water then develops. As the ice continues to melt and retract northwards, the upper layer is heated. This increases stratification, and sets necessary conditions for the spring bloom to occur in this area. In Atlantic water masses, stratification results from solar heating of surface waters. In the southern region close to the Norwegian coast, the bloom may coincide with increased stability in the water column caused by lateral spreading of water from the Norwegian Coastal Current (Rey, 1981).

As in many other ecosystems, the predominant algal group in the Barents Sea is the diatom (Rey, 1993). During the spring bloom diatoms from the genera *Chatoceros* and *Thalassiosira* are predominant in the open sea, whereas *Skeletonema* is common along the Norwegian coast. During spring bloom, the concentration of diatoms can be very high in some areas — up to several million cells per litre. Diatoms require silicate physiologically, 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*.

Species composition and abundance of the phytoplankton bloom in the Barents Sea is surveyed on a regular basis as part of the Joint Norwegian/ Russian Ecosystem Survey of the Barents Sea (ecosystem survey) during August-October; standard transects within the Fugløya-Bjørnøya and Vardø-Nord regions are covered. During these surveys, the chlorophyll concentration is measured at depths down to 100 m. These data are used to estimate biomass of photosynthetic phytoplankton in the area and to simulate primary production using numerical models.

2.4.2 Zooplankton

By T. Knutsen (IMR), P. Dalpadado (IMR) and E. L. Orlova (PINRO)

In the Barents Sea ecosystem, zooplankton form a link between phytoplankton (primary producers) and fish, mammals and other organisms at higher trophic levels. The most abundant zooplankton species — calanoid copepods, krill, and hyperiid amphipods — form the major diet of herring, capelin, polar cod, and juveniles of other fish species. The Arctic front in the Barents Sea marks the boundary between the mainly Arctic zooplankton species

(*Calanus glacialis and Themisto libellula)* and the Atlantic/subarctic species (*C. finmarchicus*, *Meganyctiphanes norvegica*, *Thysanoessa* spp and *Themisto* spp). Favourable conditions for the phytoplankton bloom/primary production at the ice edge as it retracts during summer and autumn, temporarily support large concentrations of crustaceans and other zooplankton species that are forage for seabirds, mammals, and fish. Blooms in Atlantic waters are not as intense as blooms at the ice edge; they occur over a longer period of time, however, and have higher total phytoplankton production. The spring bloom in Atlantic waters is of particular importance for reproduction of *Calanus finmarchicus* — the predominant herbivorous copepod in the central Barents Sea. It has an annual life cycle, and each new generation develops during spring and summer, being nourished by the seasonal phytoplankton bloom. Among omnivorous zooplankton, krill (e.g. *Thysanoessa* spp.) are considered most important. *Thysanoessa inermis* and *T. longicaudata* dominate the central and northwestern Barents Sea, whereas distribution of *T. rachii* is restricted to shallow waters in the southeast region. Carnivorous zooplankton such as hyperiid amphipods (*Themisto* spp.) may feed on *C. finmarchicus*; they compete with fish that consume zooplankton.

Long-term monitoring data indicate substantial year-to-year variations in indices of biomass and abundance for zooplankton in the Barents Sea (Figure 2.12 and Figure 2.13). Highest average biomass during this period was recorded in 1994 and 1995. During 1988 – 1992, average zooplankton biomass was low relative to the estimated average value for the last 11 years. A comparable trend is reflected in data from the upper water column (Figure 2.12, lower panel: 0-100 m). Data from bottom-0 m and 100-0 m indicate that by this time of the year zooplankton have initiated their seasonal vertical migration to deeper water to overwinter. It is also apparent that smaller zooplankton (180-1000 µm size fraction), are more abundant in 0-100m depth interval, and are more important in the upper water column during this time of the year.

Gelatinous zooplankton is a term often used expression by non-specialists in reference to classes of organism that are jelly-like in appearance. The term "jellyfish" is commonly used in reference to marine invertebrates belonging to the class Scyphozoa, phylum Cnidaria. Neither of these terms implies any systematic relationship to vertebrate fish. The term "jellyfish" is also often used in reference to relatives of true scyphozoans, particularly the Hydrozoa and the Cubozoa. In the Barents Sea ecosystem, however, comb-jellies (phylum Ctenophora) and cnidarian (phylum Schyphozoa) are predominant species of "gelatinous zooplankton". There is no available time series of data to describe these organisms in the Barents Sea. Both comb-jellies (Ctenophora) and "true" jellyfish are predators and many compete with plankton-eating fish, as copepods often are significant prey items for both groups. Along with increased temperatures, and changes in other components of the Barents Sea ecosystem, research interest has also increased to understand how these changes effect abundance and distribution of gelatinous zooplankton. A preliminary overview of this ecosystem component is presented in section 4.4.1.3 of this report.

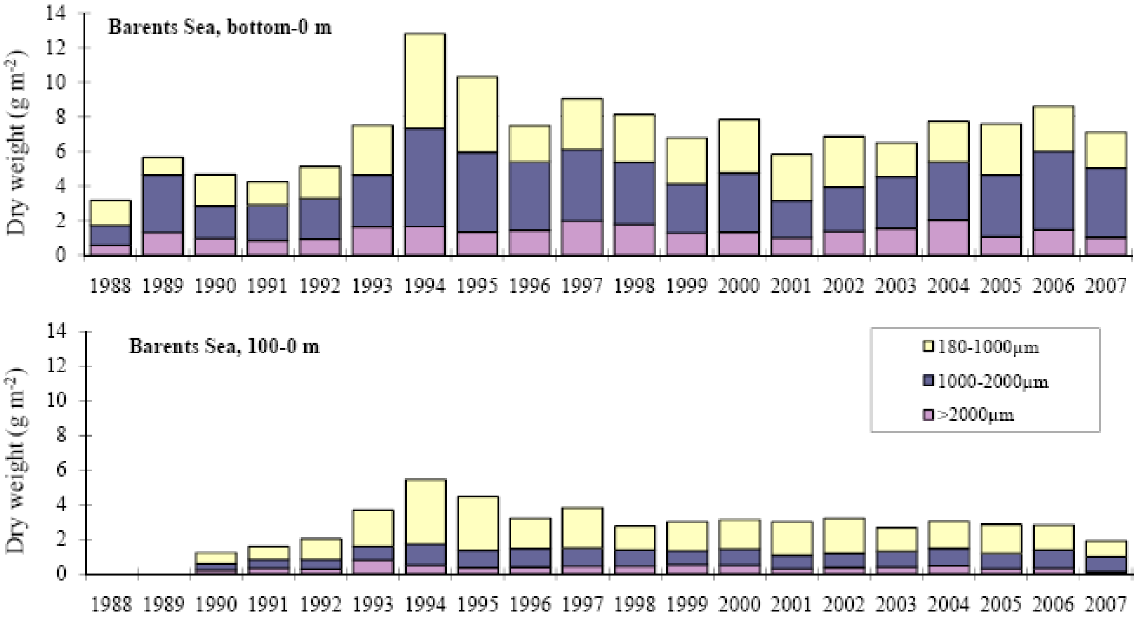

Figure 2.12. Long-term size composition of zooplankton biomassin the water column from bottom-0 m (top) and 100-0 m (bottom) in the Barents Sea. Size fractioned samples collecting using a WP2-net.

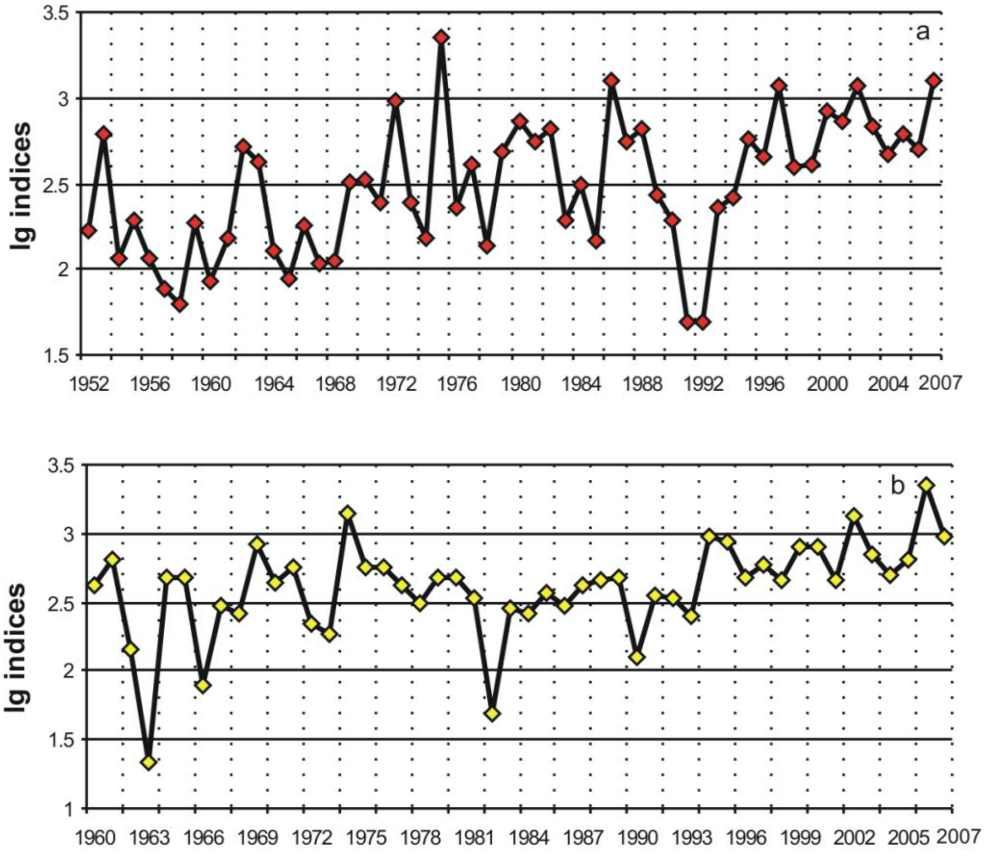

Figure 2.13. Variation in abundance indices of krill in southern (a) and northwestern (b) regions of the Barents Sea (data from macroplankton survey conducted by PINRO).

2.4.3 Benthos

By L.L. Jørgensen (IMR), N. A. Anisimova (PINRO), P. A. Liubin (PINRO) and
I. E. Manushin (PINRO)

Invertebrate benthos are distribution on, inside, or just above the sea bottom. Several bottom-dwelling species are are anchored to or crawling on the sea floor; others live inbetween already existing communities of benthic animals, thus creating multi-species habitats. This community of bottom-dwellers is referred to as the “epibenthos”. Many of these species are large, conspicuous, and robust, including: sea stars; brittle stars; sea cucumbers; sea lilies; crangonid prawns; isopods; sponges; corals; molluscs; and sea anemones. This group of individuals is referred to as the “mega epibenthos” because they are larger than 4 cm. Several species within this group have limited movement, and a long life span; they can be found in the same areas year after year.

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

Major Russian studies conducted from the 1930´s to the 1990´s indicated significant spacial variation in benthic biomass — ranging from <10 to >500g WW m^{-2} — with highest levels occuring in shallows of Spitsbergen Bank, Central Bank, and banks within the Russian Zone. These high biomass levels were likely linked to high primary production at Western Banks, combined with strong water currents that resuspended food items and hard substrate to supportlarge numbers of sessile filter feeders (Wassmann et al 2006).

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

The biomass of echinoderms is highest in western and central regions of the Barents Sea; the biomass of bivalves is highest in southeastern regions. The western region is generally deeper, is rich in echinoderms, and relatively poor in polychaetes. When focusing on “number of individuals (abundance). The bivalves are typically reduced with increased depth, whereas echinoderm abundance increases with increased depth; polychaete abundance remains essentially unchanged with increased depth (Zenkevitch 1963).

2.4.4 Shellfish

By *J. Sundet (IMR), C. Hvingel (IMR), P.A. Liubin (PINRO), V. A. Pavlov (PINRO) and M.A. Pinchukov (PINRO)*

Shellfish are an essential component of the benthic ecosystems. At present, however, only three species are of major economic importance in the Barents Sea: deep sea shrimp (*Pandalus borealis*); Iceland scallops (*Chlamys islandica*); and red king crab (*Paralithodes camchaticus*) which were successfully introduced in the 1960s. These three species are described below.

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

Abundance of snow crabs *(Chionoecetes opilio)* — first reported in the Barents Sea in 1996 — has increased significantly in recent years. There are two existing hypothesses concerning this introduction. The first is that larvae from the northern Atlantic are transported in the ballast water of shipping tankers, and the second that there are migration from the Pacific westward through waters north of Russia.. A rapid widening of its distribution, and increased abundance, indicate successful adaptation of this species to the Barents Sea. Its increased commercial importance is expected.

2.4.4.1 Deep sea shrimp (Pandalus borealis)

The deep sea shrimp (*Pandalus borealis*, also called deepwater shrimp or Northern shrimp) are distributed in most deep waters of the Barents Sea and Svalbard. The densest concentrations are found in the central region of the Barents Sea, Hopen Deep, and Thor Iversen Bank at depths from 200 to 350 meter (Hvingel, 2006), and near the western Murman coast (Figure 2.14). The fishery is conducted primarily using large (>2000 GRT) trawlers; annual total catch has ranged from 40,000-130,000 tons since the early 1980s. Stock size was estimated at 577,000-990,000 tons using Russian survey data fromthe 1998-2005 period.

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

2.4.4.2 Red king crab (Paralithodes camtschticus)

Red king crab (*Paralithodes camschaticus*) was deliberately introduced to the Barents Sea through various mechanisms during the 1960s and 1970s (Orlov and Ivanov 1978). Since then, the crab's distribution has spread widely both east- and west, and is now common throughout the southern Barents Sea — from Cape Kanin in the east to North Cape/Hammerfest in the west (Figure 2.15). The crab is also expected to spread northwards.

Red king crabs are the largest crustaceans in the Barents Sea. With high abundance and large size, this species strongly influences trophic dynamics and functioning of bottom communities in the southern Barents Sea. Red king crab feed on a variety of prey species; polychaetes, bivalves, and echinoderms predominate in the contents of stomachs analysed (Sundet et al. 2000). Juvenile red king crabs are preyed upon by most bottom-feeding fish species. As the crab becomes larger however, it has few if any predators in the Barents Sea ecosystem. Studies thus far indicate no major impact to bottom communities where this species has been introduced, and inhabited for decades (Anon. 2005). Additional study will be required, however, before this question can be fully addressed.

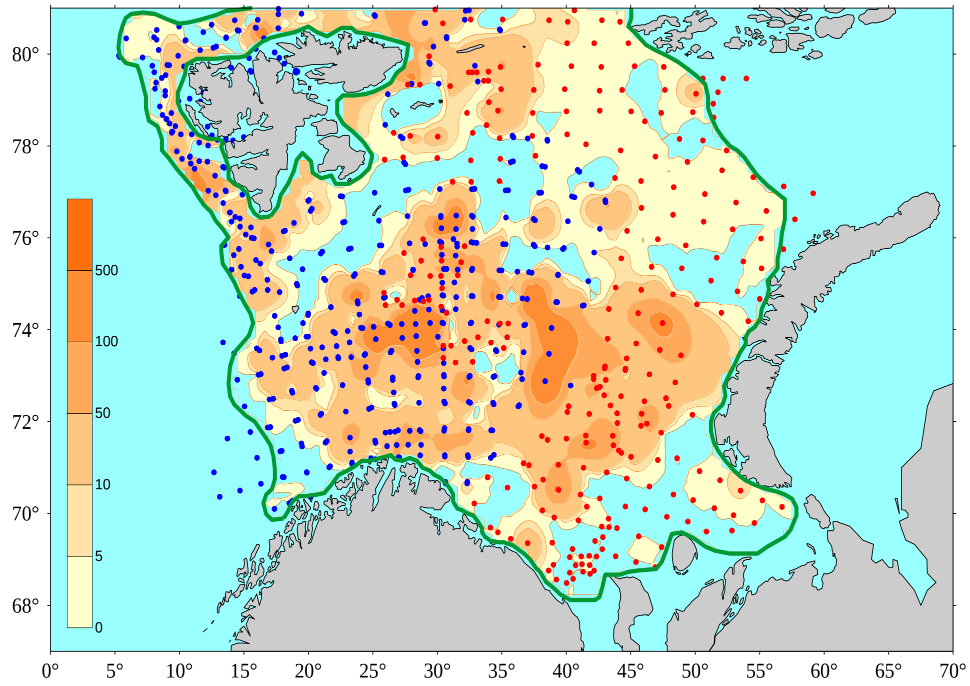

Figure 2.14. Distribution of northern shrimp in the Barents Sea and Svalbard region. Survey trawl hauls (blue and red dots) and of estimated densities (kg/hour trawed) from the Joint Noregian Russian Ecosystem Survey during August-September 2007.

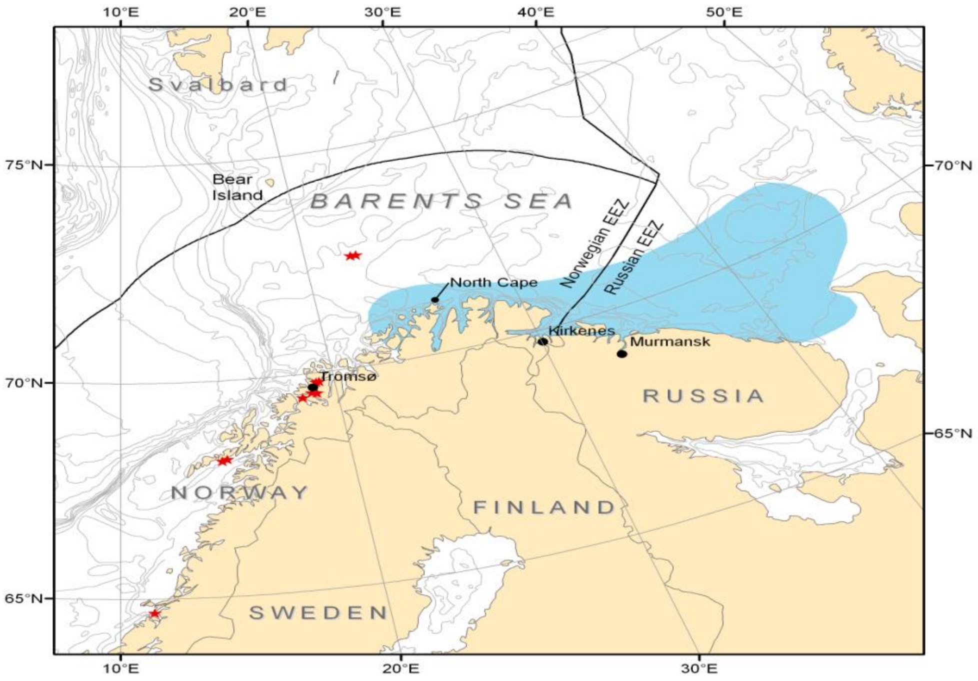

Figure 2.15. Distribution of Red king crab in the northern Atlantic region. Red asterisks indicate areas where crabs have been observed.

The total stock of red king crabs estimated in 2006 was approximately 14 million specimens (Sundet and Sokolov 2006); this estimate is based on crabs larger than 70 mm (carapace length) due to limited catchability of juvenile crabs to survey trawl gear. A fishery for this species in the Barents Sea was initiated in 1994 on an experimental basis in both Norwegian and Russian zones. In Norwegian waters, only small coastal vessels are allowed to participate, and management options are still under consideration. In Russian waters, a licensed comercial fishery was introduced in 2004, which is managed to maintain the stock;

2.4.4.3 Snow crab (Chionoecetes opilio)

The Barents Sea snow crab (*Chionoecetes opilio*) is native to waters in Alaska, on the east coast of Canada, and west of Greenland; it supports important fisheries in each of these regions. This species reaches a smaller maximum size than the red king crab (*Paralithodes camtschticus*) — a species that was deliberately introduced into the Barents Sea — and has a different biology/life history (Elner and Beninger 1995).

The Barents Sea snow crab is therefore considered an invasive species. After the first recorded observations of snow crabs on Goose Bank in 1996, reports of snow crab by-catch in the bottom-trawl fishery have gradually increased. Since 2003, snow crabs have been found in stomachs of cod, haddock, catfish, and thorny skates. This indicates that snow crab abundance and settlement density have increased substantially. In 2005, snow crabs were first recorded in trawl catches of the Joint Norwegian/Russian Ecosystem Survey in the Barents Sea. They were distributed widely, with highest concentrations in the southeastern region (Alvsvåg et al 2008). In subsequent annual ecosystem surveys, both abundance and spatial distribution of snow crabs have increased (Figure 2.16).

At present it is uncertain if the snow crab population will increase in size and distribution enough to sustain a fishery equal to that of the red king crab. Investigations indicate that environmental conditions such as variation in temperature range could possibly limit further dispersal. It will be important, however, to implement a monitoring program for the introduced snow crab to evaluate potential ecological consequences (Alvsvåg et al 2008).

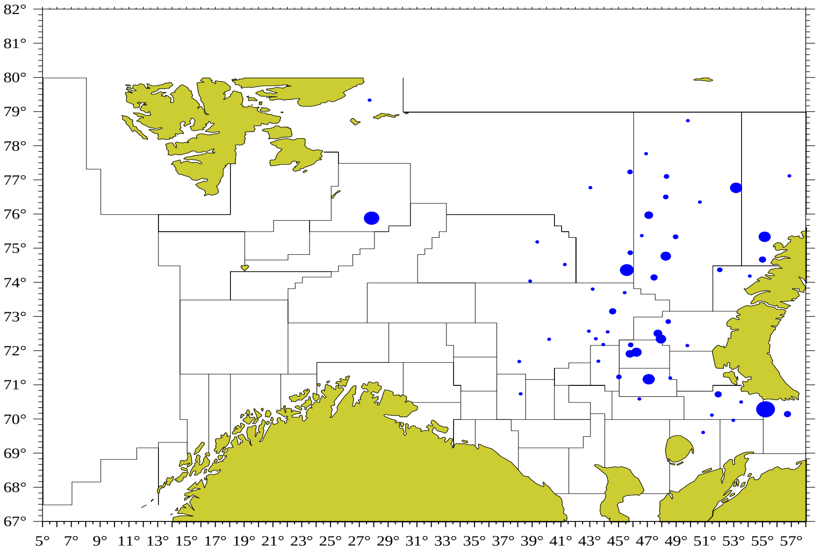

Figure 2.16. Distribution of snow crab (ind./tow) based on 2007 Ecosystem Survey results (Circle diameter corresponds to the number of crabs (1 to 11 individuals) per tow.

2.4.4.4 Iceland scallop (Chlamys islandica)

The Iceland scallop (*Chlamys islandica*) is a slow-growing species common to shallow waters (< ca 150 m) of: the Svalbard region; coastal waters of Kola Peninsula; and northern Norway (Wiborg 1963, 1970, Wiborg et al 1974, Rubach and Sundet 1987) (Figure 2.17). It is usually foundon hard bottom substratey in areas with strong currents (Wiborg 1963). It is a filter feeder; therefore its growth is linked to seasonal phytoplankton production (Sundet and Vahl 1981). In the Spitsbergen region the scallop grows slowly, and may reach 30 years in age (Rubach and Sundet 1987). Unpublished data also reveal that recruitment to the different stocks may vary significantlybetween periods.

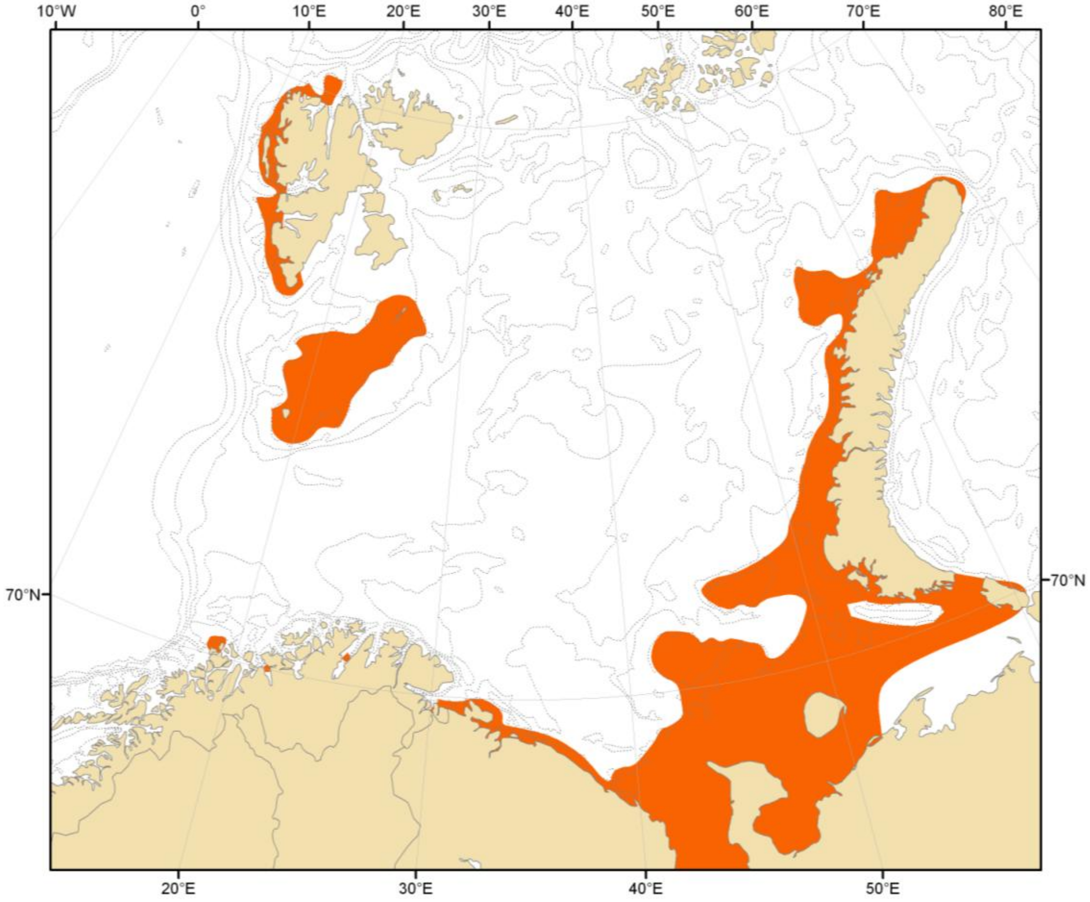

Figure 2.17. Distribution of Iceland scallops.

In the Russian Economic Zone (REZ), the scallop occurs in high densities along the coast of Novaya Zemlya archipelago, the Kola Peninsula, as well as on Goose Bank, North Kanin Bank, and Kanin Bank (see figure 5.45). Intense fishing for the Iceland scallop in the Barents Sea and Spitsbergen region was carried out from 1986 to 1992 by Norway and other countries. All scallop beds dense enough to attract fishermen were virtually eradicated. More than 4,000 tons of scallops were landed in 1987 from this area. Near-shore fisheries for this species are also conducted along the Murmansk coast, and near Tromsø in Norway.

Scallop abundance and distribution was monitored the period of heavy exploitation between 1986 and 1992. The most extensive beds were found north of Bear Island, and close to Moffen Island north of Svalbard, but all scallop beds were overfished during this period.In 1992, within the Norwegian Economic Zone (NEZ), a moratorium was imposed on the fishery. Since then, regular surveys have been conducted by the Institute of Marine Research

(IMR) in Norway, and the Polar Institute of Marine Fisheries and Oceanography (PINRO) in Russia to monitor recovery of the stock.Within the Russian Economic Zone (REZ), the fishery for Icelandic scallops has been ongoing since 1987; since that time the recorded maximum annual Russian catch was 14,000 tons during 2001

2.4.5 Fish species

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2.4.5.1 Species diversity, assemblages and zoogeography

Nearly 100 fish species occur regularly in trawl catches during surveys of the Barents Sea. Total biomass and abundance is dominated by few species; in bottom trawls during the ecosystem survey (August-September 2007), the ten most abundant fish species constituted over 90% of total abundance for all species caught (Figure 2.18).

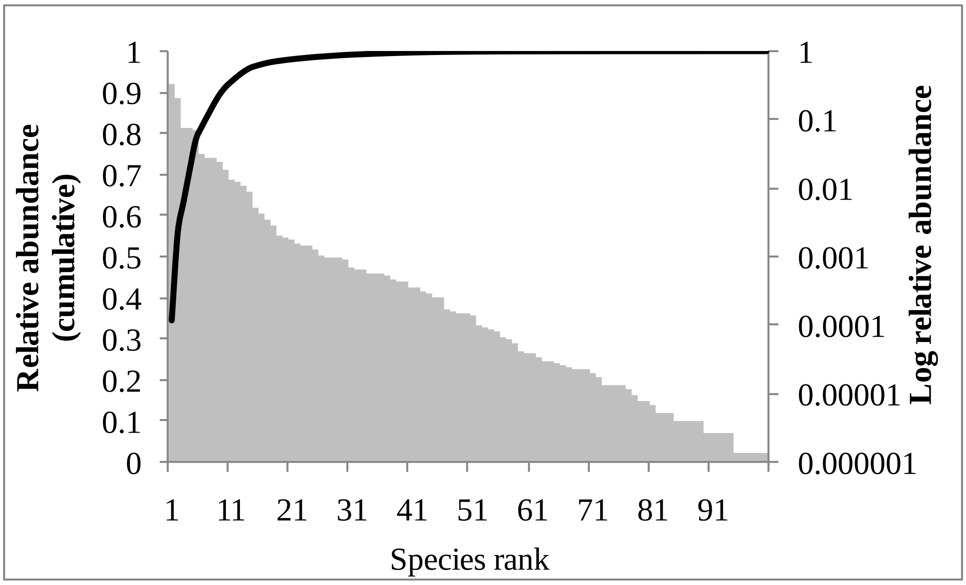


Figure 2.18. Cumulative relative abundance and relative log abundance plotted against species rank (Whittaker plot) for fish species in bottom trawl catches during the ecosystem survey (August-September 2007).

The Appendix to this report provides an updated list of all recorded species in the Barents Sea. It should be noted, however, that: some records need to be validated due to taxonomic uncertainty.. Nevertheless, the appendix lists 204 different species, from 70 families. The predominant families are: eelpout (*Zoarcidae);* codfish *(Gadidae);* sculpin (*Cottidae*); snailfish (*Liparidae);* skate *(Rajidae*); flatfish (*Pleuronectidae*); and rockling, ling, and tusk (*Lotidae).* These families account for nearly 80 % of all species regularly occurring in the Barents Sea, and 42% of all species ever recorded in this region.

Different species of fish are not evenly distributed throughout the Barents Sea. Rather, they exhibit highest abundance in areas with suitable environmental conditions. Different water masses, i.e. coastal water, Atlantic water, Arctic water, and waters in frontal zones between these water masses, combined with bottom type, depth, are important factors that determine distribution and abundance of fish species. For pelagic species, distribution and abundance of zooplankton is also a very important factor. Species with similar habitat requirements co-occur within delineated geographical areas, and form fish assemblages, with distinct species compositions. Figure 2.19 displays how different demersal fish assemblages were distributed within the Barents Sea during August-September 2007. There is a distinct species group north of the Polar Front in Arctic water, two frontal groups (one deep and one shallow), and one group in the southwest along the shelf associated with warmer Atlantic water. There are also several coastal groups, along Spitsbergen, the Norwegian coast, the Murman coast, and the coast of Novaya Zemlya archipelago. Each of these groups is characterized by a unique species composition, and by relative abundances of species present.

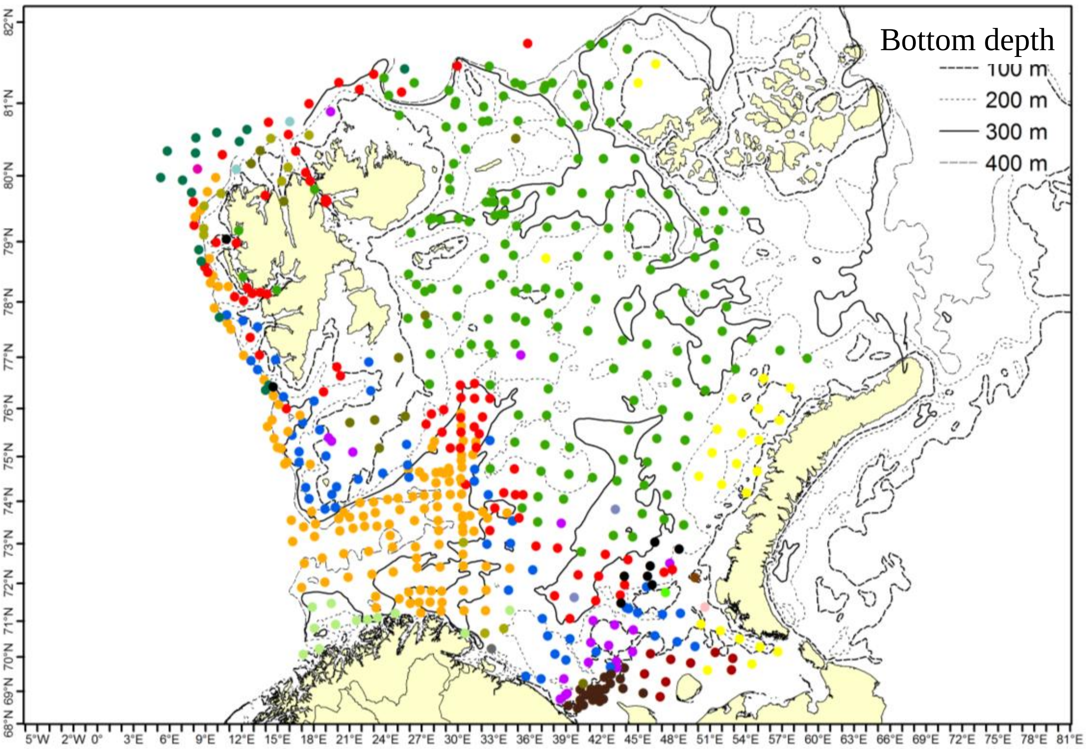


Figure 2.19. Bottom trawl stations grouped by demersal fish species composition. Abundance data from bottom trawl catches during the ecosystem survey. Non-representative samples were excluded, leaving a total of 581 bottom trawl stations. Fifteen pelagic species were excluded from the analysis, leaving 77 species or species groups. Cluster analysis was done using PRIMER software, applying Bray Curtis similarity and a 90% cut-off level for low contributions. Abundance data (number of individuals per haul) was standardized into numbers per 3 nautical miles towed (i.e. comparable with 1 hour trawling) and log transformed. The three most abundant species (cod, haddock and long rough dab) were excluded from the analysis. These species are abundant and ubiquitous in the entire survey area; analyses that incorporated these species reflected variation in their abundance, but did not reflect variation in the overall species composition, assemblage structure, and distribution.

Andriyashev and Chernova (1995) classified 166 Barents Sea fish species into seven zoogeographic groups as follows (Table 2.1;
Figure 2.20):

- 27% Arctic, Mainly Arctic or Arcto-boreal
- 48% Mainly Boreal or Boreal
- 25% South Boreal or Widely Distributed

When only species that occur regularly were considered, the relative importance of different groups changed (Appendix):

- 36% Arctic, Mainly Arctic or Arcto-boreal
- 55% Mainly Boreal or Boreal
- 9% South Boreal or Widely Distributed

Of the fish species recorded at the ecosystem survey in autumn 2007:

- 34% Arctic, Mainly Arctic or Arcto-boreal
- 55% Mainly Boreal or Boreal
- 11% South Boreal or Widely Distributed

All fish species described in this report (sections 0 to 0) are classified as Mainly Boreal — other than polar cod (*Boreogadus saida*), which is classified as Arctic species (Appendix 1). Occurrence in the Barents Sea of boreal, south boreal, and widely distributed fish species is expected to increase in the coming years, due to increasing temperature, increased inflow of Atlantic water, and the northward expansion in range of distribution for a number of species typically found in southern regions.

Table 2.1. Definition of zoogeographical fish groups

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

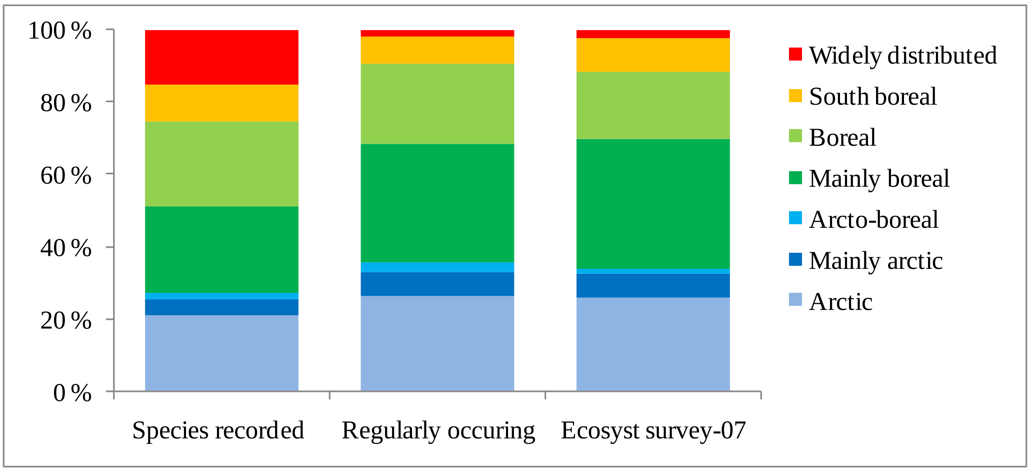


Figure 2.20. Fish species recorded in the Barents Sea (n=166) by Andriyashev and Chernova (1995), fish species regularly occurring (n=107) and fish species recorded during the ecosystem survey in 2007 (n=86), classified by zoogeographical group.

2.4.5.2 Main fish species – stock size and fluctuations

Principal demersal stocks of economic importance are cod, haddock, redfish (mainly deep-sea redfish, *Sebastes mentella*), Greenland halibut, long rough dab, wolffish and European plaice (*Pleuronectes platessa*). Analytical assessments have not been conducted on long rough dab, wolfish,and plaice. The main pelagic stocks are capelin, polar cod and immature Norwegian Spring-Spawning herring. The last few years there has in addition been a high abundance of blue whiting in the western Barents Sea. These species have shown significant variations in abundance (Figure 2.21 and Figure 2.22). These variations are due to a combination of fishing pressure and environmental variability. Until the 1970s the deep-sea redfish was an abundant stock in the Barents Sea. Due to heavy overfishing the stock declined strongly during the 1980s, and has since remained at low levels.

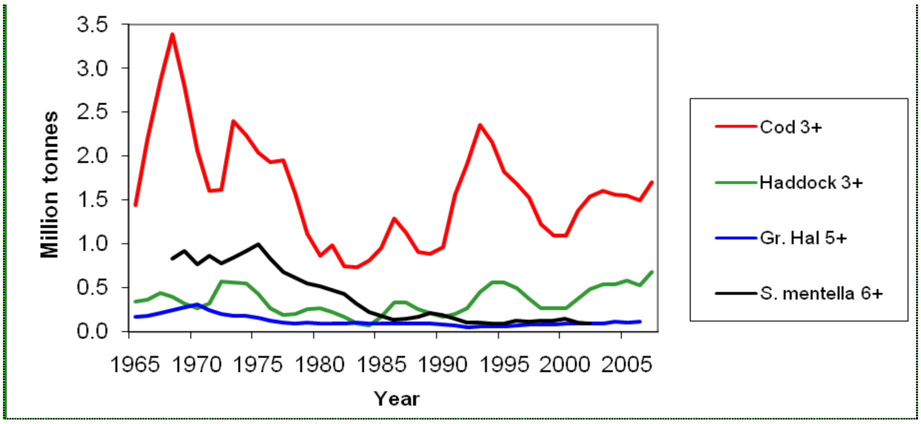


Figure 2.21. Biomass of demersal fish species in the Barents Sea. Data are taken from; cod: VPA estimates, age 3+ (ICES, 2008); haddock: VPA estimates, age 3+ (ICES, 2008); Greenland halibut: VPA estimates, age 5+ (ICES, 2007); Sebastes mentella: VPA estimates, age 6+ (ICES, 1995 for the years 1968-1990; ICES, 2003 for the years 1991-2002).

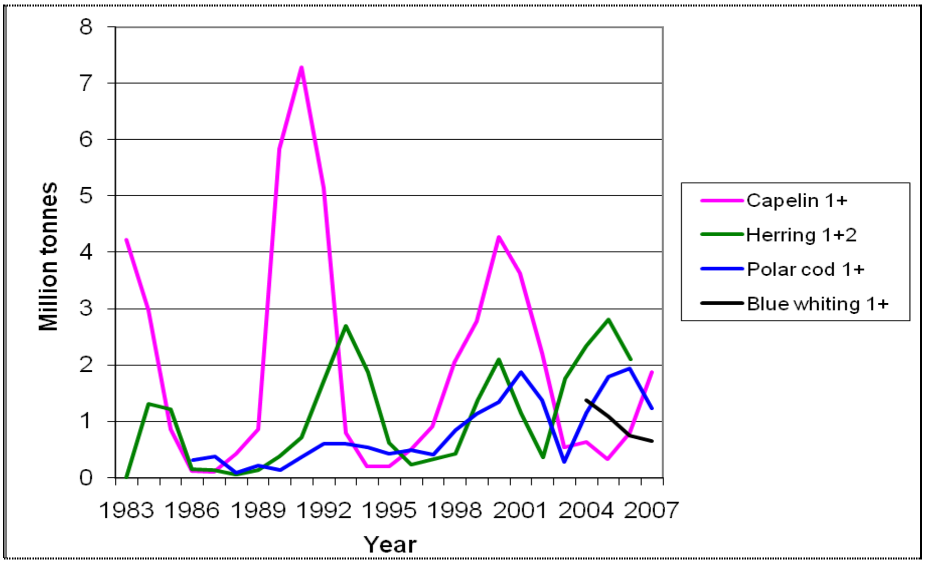


Figure 2.22. Biomass of pelagic fish species in the Barents Sea. Data are taken from; capelin: Acoustic estimates in September-October, age 1+ (ICES AFWG 2008;, herring: VPA estimates of age 1 and 2 herring (ICES WGNPBW 2007) using standard weights at age (9 g for age 1 and 20g for age 2); polar cod: Acoustic estimates in September-October, age 1+ (Anon., 2007); blue whiting: Acoustic estimates in September-October, age 1+ (Anon., 2007).

Recruitment of Barents Sea fish species has significant interannual variability (Figure 2.23). Factors contributing to this variability include: spawning stock biomass; climate conditions; food availability; and abundance and distribution of predators. Variation in recruitment of some species, including cod and herring, has been associated with changing influx of Atlantic waters into the Barents Sea.

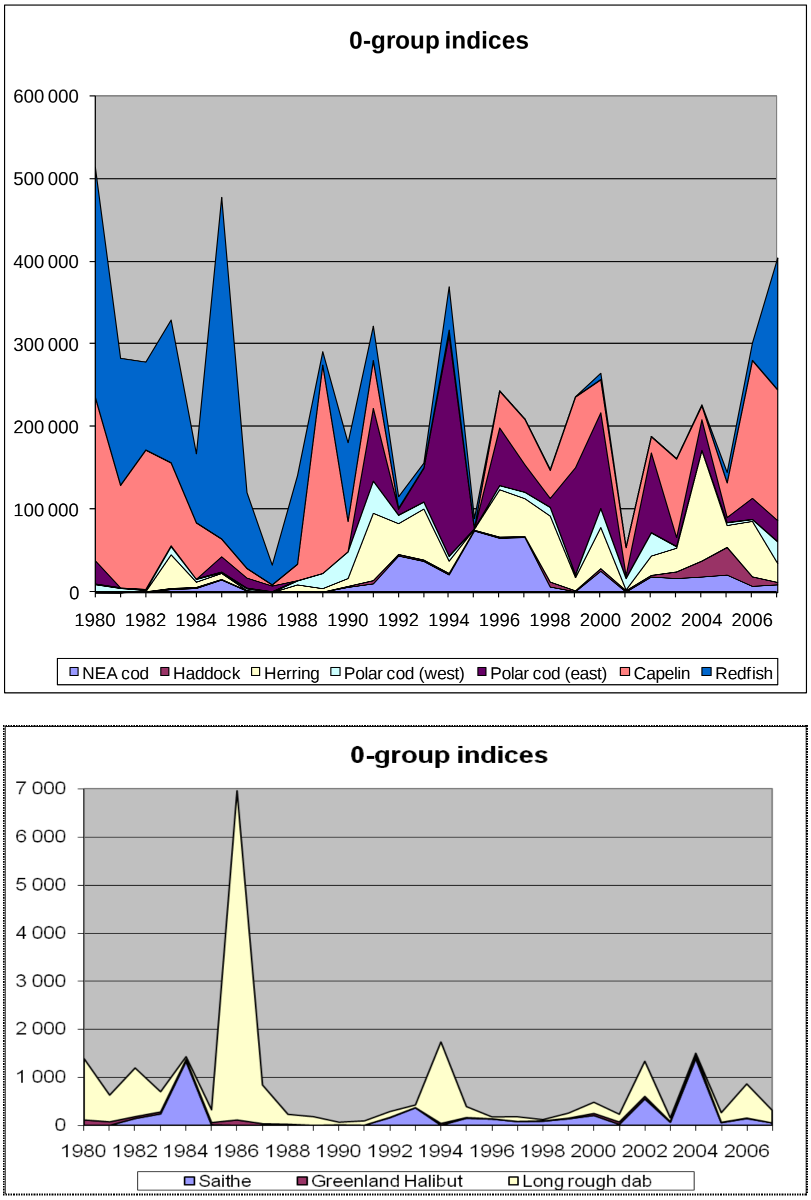


Figure 2.23. 0-group abundance indices (in millions of individuals) not corrected for catching efficiency. Note that vertical axes differ between the two panels.

2.4.5.3 Cod (Gadus morhua)

Adult cod have an annual spawning migration from the Barents Sea to the western coast of Norway. Spawning largely occurs in the Lofoten area during March-April. Cod larvae are advected with the Norwegian coastal current and Norwegian Atlantic current back to the Barents Sea where they settle at the bottom around October. Cod is a keystone species and the most important predatory fish in the Barents Sea. It feeds on a wide range of prey, including: larger zooplankton species; most available fish species; and shrimp. Cod prefer capelin as prey, and feed on them heavily as they migrate into southern and central regions to spawn. Capelin stock fluctuations strongly effect cod growth, maturation, and fecundity;they also indirectly affect cod recruitment, as cod cannibalism is reduced in years with high capelin biomass. Euphausiids are also important prey for cod during the first yearof life Ponomarenko (1973, 1984); in years when the capelin stock is low, cod predation on euphausiids increases (Ponomarenko and Yaragina 1990).

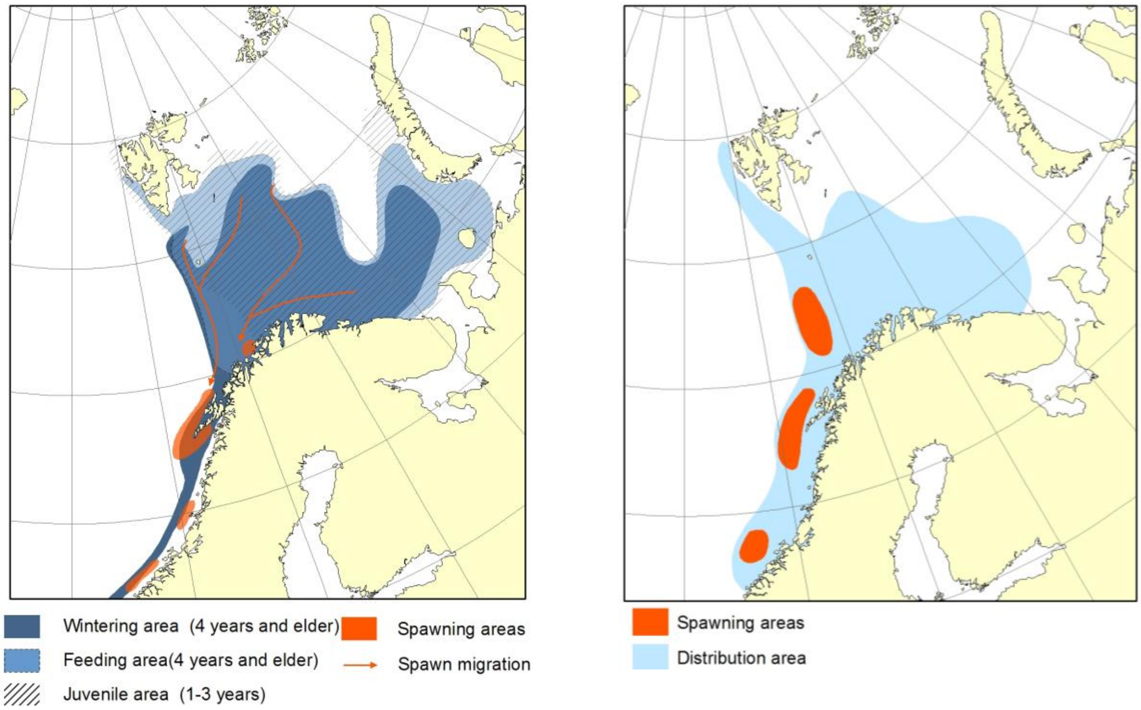


Figure 2.24. Distribution area for Northeast Arctic Cod (left) and Northeast Arctic Haddock (right).

2.4.5.4 Haddock (Melanogrammus aeglefinus)

Haddock is an important demersal gadoid species that undertakes extensive migrations to and from its spawning grounds in the Barents Sea (ICES c2007-2008). Variation in recruitment of haddock has been associated with changes in the influx of Atlantic waters to the Barents Sea. Water temperature at the first and second years of the haddock life cycle is an indicator of year class strength; during this period of its life cycle if mean annual water temperature in the bottom layer does not exceed 3.8^{o}C the probability of having a strong year class is low, even if other remaining factors are favourable. Water temperature is not a consistent determinant of year-class strength; however, a steep rise or fall in water temperature can have a marked effect. Haddock feed primarily on relatively small benthic organisms including crustaceans, molluscs, echinoderms, worms, and fish. They are omnivorous, however, and also feed on plankton. During capelin spawning, haddock prey on capelin and their eggs. When capelin abundance is low, or when their areas of distribution do not overlap, haddock may switch to other fish species, i.e. young herring, or consume euphausiids and other benthic organisms (Zatsepin 1939; Tseeb 1964). Haddock stock size large natural variation, and is believed to be density-dependent. Similar to cod, annual consumption of haddock by marine mammals (primarily seals and whales) depends on the availability of capelin. During years when the capelin stock is large, the importance of haddock in the diet of marine mammals is minimal; when the capelin stock is reduced, the proportion of haddock in the diet of marine mammals increases.

2.4.5.5 Redfish (Sebastes mentella and Sebastes marinus)

Deep-sea redfish (*S. mentella*) and golden redfish *(S. marinus)* have traditionally been important fish species in the Barents Sea ecosystem; current stock levels, however, have been severely reduced. Young redfish are plankton eaters (Dolgov and Drevetnyak, 1995); larger individuals take larger prey, including other fish species (Dolgov and Drevetnyak, 1993). Until 1990, huge amounts of redfish postlarvae filled the pelagic Barents Sea every summer and autumn. These 0 age-group redfish consumed plankton, and were consumed other by other larger fish species. It is unknown if the niche once filled by redfish has been taken over by other plankton feeders. Since redfish are viviparous and give birth to live larvae, a strong relationship is believed between age composition of the spawning stock and levels of recruitment. Low abundance of redfish larvae and juveniles in the Barents Sea is believed to indicate low spawning stock size. Fisheries for both these species are currently restricted in order to rebuildspawning stock size; this isexpected to improve conditions and lead to increased stock production.

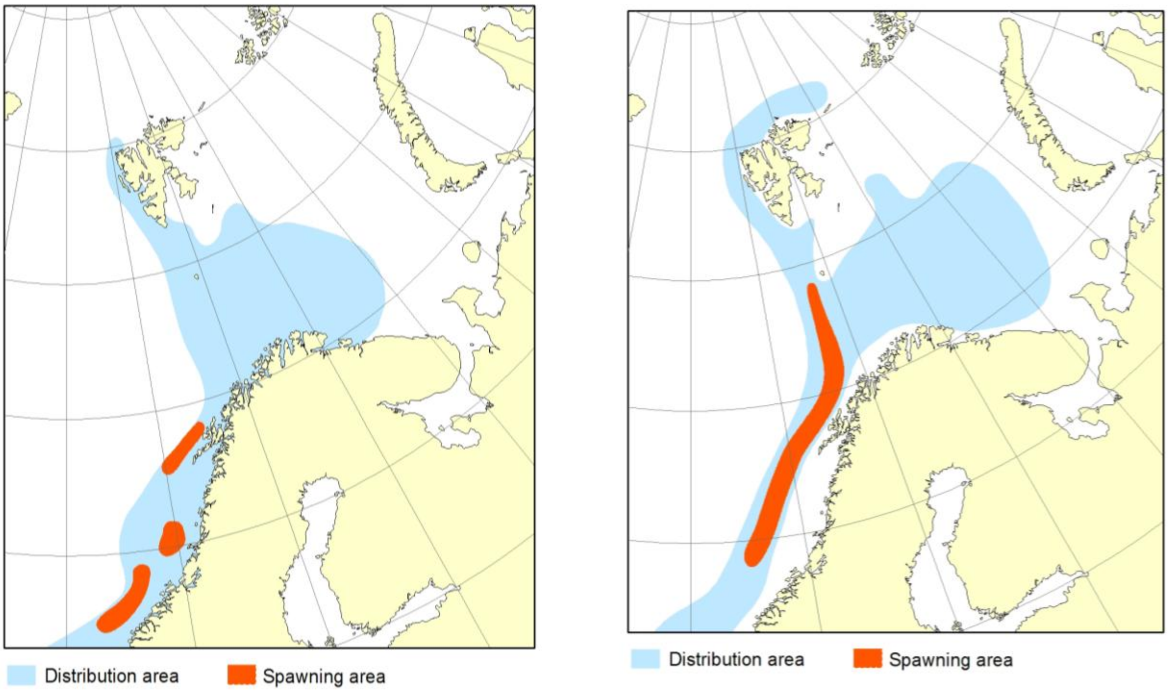


Figure 2.25. Distribution area for golden redfish (left) and Deep Sea redfish (right) in the Barents Sea region.

2.4.5.6 Greenland halibut (Reinhardtius hippoglossoides)

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

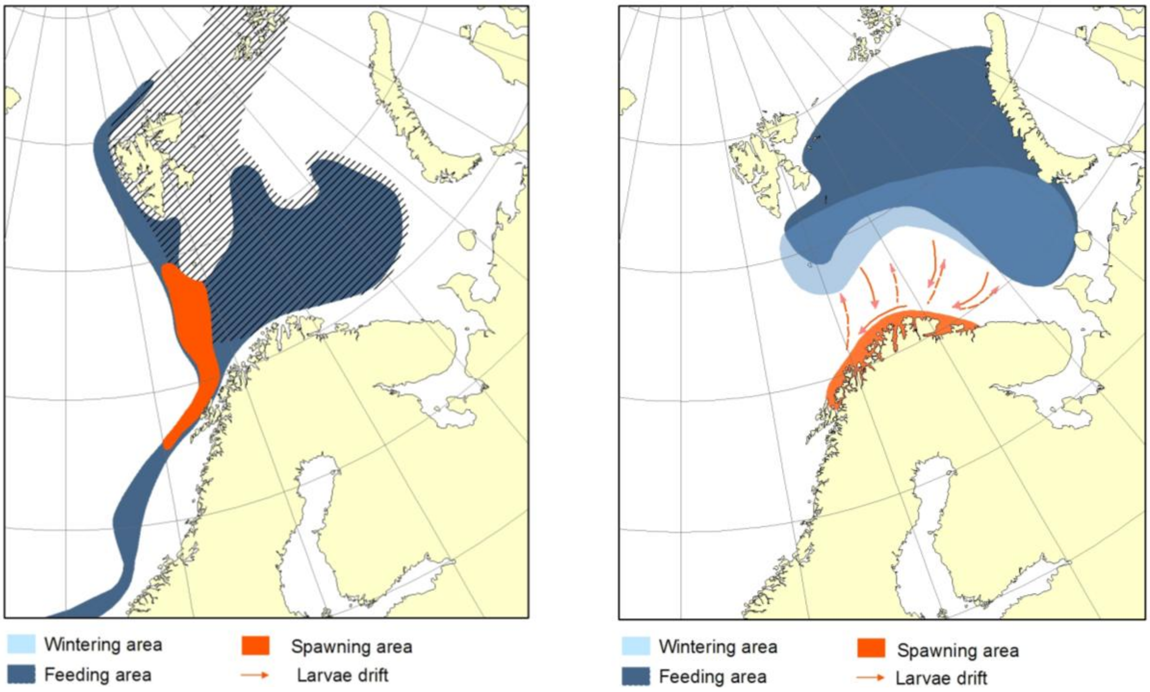


Figure 2.26. Distribution area for Northeast Arctic Greenland halibut(left) and Barents Sea capelin (right). Please note that the arrows also denote the adult spawning migration for capelin.

2.4.5.7 Capelin (Mallotus villosus)

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

2.4.5.8 Herring (Clupea harengus)

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

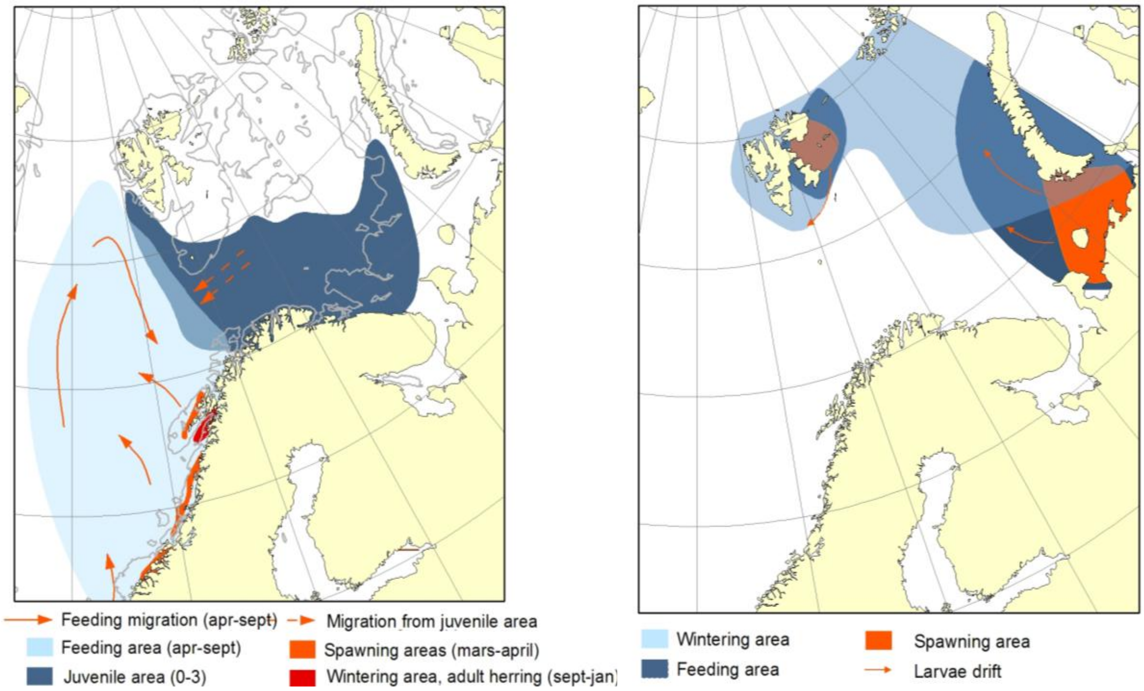


Figure 2.27. Distribution area for Norwegian spring spawning herring (left) and polar cod (right).

2.4.5.9 Polar cod (Boreogadus saida)

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

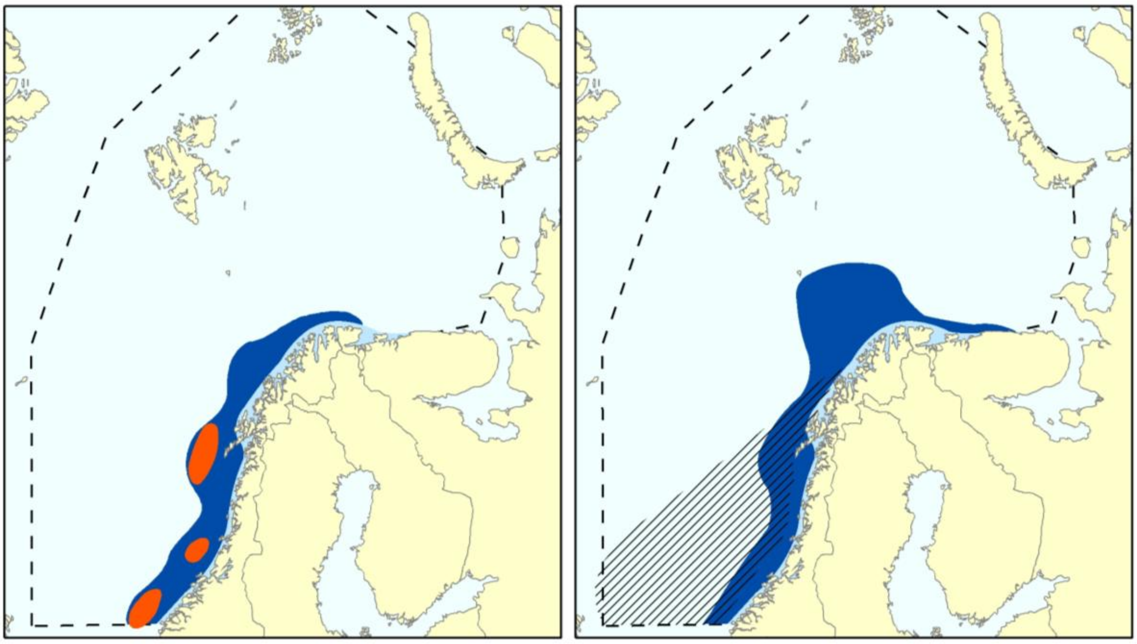
2.4.5.10 Blue whiting (Micromestisius poutassou)

The blue whiting is mainly distributed in the Norwegian Sea, the northeast Atlantic. The marginal northern extent of its distribution is at the entrance to the Barents Sea; its population there is relatively small. During years with inflow of warm Atlantic water masses, blue whiting may enter the Barents Sea in large numbers; they can be a predominant species in western areas. Such a situation occurred during 2000-2001; subsequent blue whiting abundance has been significant (Belikov et al., 2004). During its early life history (until age 5), this species is primarily a plankton feeder; its food preferences become more piscivorous during its life cycle (Belikov et al., 2004). In 2004, blue whiting biomass was estimated to be 1.4 million tons, mostly fish aged 1-4. This made it the second most abundant pelagic plankton-feeding fish species that year; the highest estimated abundance was young herring; the third and fourth most abundant species were polar cod, and capelin, respectively. Historically, capelin and young herring have been predominant plankton-feeding fish species. The general distribution pattern for these four species has only minimal overlap: blue whiting in the west; herring in the south; polar cod in the east (some overlap in the Spitsbergen region); and capelin in the north. In the south-western region, blue whiting and herring may overlap in their area of distribution, but they tend to occupy different depths in the water column. Their lack of overlap with other predominant pelagic species — both in area of distribution and depth of water column — indicates low interspecific competition in feeding on the local zooplankton.

Figure 2.28. Distribution area for blue whiting.

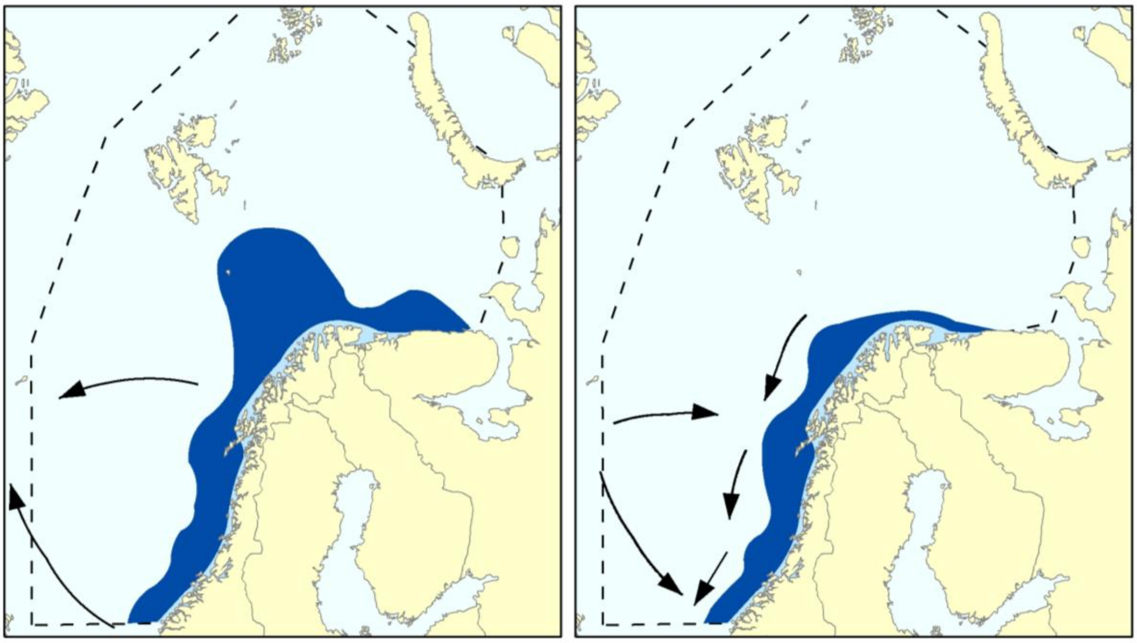
2.4.5.11 Saithe (Pollachius virens)

Saithe is a boreal species found in north Atlantic waters. In the northeastern Atlantic saithe is separated into six stocks: 1) west of Ireland; 2) west of Scotland; 3) at Iceland; 4) at the Faeroe Islands; 5) in the North Sea; and 6) northeast Arctic saithe — along the coast of Norway (62° N at Møre to Kola Peninsula) and the southeastern Barents Sea. It also occurs at Svalbard in low abundance. Tagging experiments indicate that saithe make both feeding and spawning migrations; there are also migrations between stocks. Young saithe may migrate extensively from the western Norwegian coast to the North Sea.Adults follow Norwegian spring-spawning herring far out into the Norwegian Sea, sometimes all the way to Iceland and Faeroe Islands. There are, however, few examples of migration in the opposite direction, i.e. to the Norwegian coast. Saithe are both pelagic and demersal, found at depths from 0-300 m. They often occur in dense concentrations, e.g. in the pelagic zone where currents concentrate prey items. Predominant prey items for young saithe are *Calanus*, krill, and other crustaceans; with age they become increasingly piscivoroug and prey on: herring; sprat; young haddock; Norway pout; and blue whiting. In the northeast Arctic saithe spawn during winter; the peak is during February at depths from 150-200mand temperatures from 6–10 ˚C. Theytake regular annual spawning migrations from the northern coast of Norway to spawning areas off the western coast of Norway; they sometimes migrate to northern regions of the North Sea, but to a lesser extent. Principal spawning areas are: Lofoten; Haltenbanken; and banks outside Møre and Romsdal region in the Sunnmøre archipelago. Eggs and larvae drift northward with the currents, 0 age-group saithe use as nursery grounds shore areas extending on the western coast of Norway to southeastern regions of the Barents Sea; they migrate to coastal banks as 2–4 year olds.



Saithe 1.quarter

Saithe 2.quarter



Saithe 3.quarter

Saithe 4.quarter

Figure 2.29. Distribution of saithe larvae, juveniles, age 3+, spawning areas and main migration patterns by quarter.

2.4.5.12 Wolffish (Anarhichas spp.)

Three species of Anarhichas (common wolffish- *Anarhichas lupus*, spotted wolffish- *A. minor* and northern wolffish- *A. denticulatus*) inhabit the Barents Sea and adjacent waters. Wolffish are large (up to 180 cm), long-lived (up to 25 years), and demersal. These life-history traits make them vulnerable to exploitation.

Common wolffish inhabit areas (Figure 2.30) close to shore, including bays. Adult fish have solitary, territorial life patterns, but carry out limited seasonal migrations. Adults spawn close to shore during summer through autumn at depths up to 130 m.

Spotted wolffish inhabit offshore area (Figure 2.30) at 50 to 500m depths. Their range coincides mostly with that of cod (*Gadus morhua*). In the Barents Sea spotted wolffish carry out extensive (up to 1200 km) seasonal migrations. Their spawning takes place over a period extending from April to September, with peak during July-August in south-western regions of the Barents Sea shelf.

Northern wolffish have a more western distribution (Figure 2.30) than spotted wolffish. Seasonal migrations are carried out that extend out beyond the Barents Sea shelf. Spawning occurs in the south-western region of the Barents Sea shelf at depths lower than spotted wolffish.

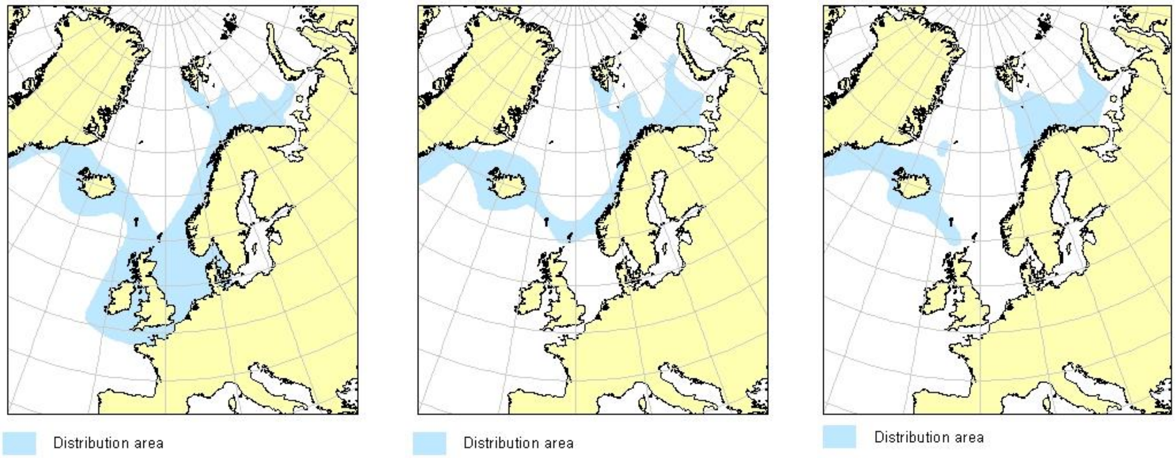


Figure 2.30. Distributions of wolfish. Left panel is common wolffish (based on Whitehead et al. 1986). Middle panel is spotted wolffish (based on Whitehead et al. 1986, modified by Byrkjedal and Høines 2007). Right panel is northern wolffish (based on Whitehead et al. 1986, modified by Byrkjedal and Høines 2007)

2.4.5.12 Long rough dab (Hippoglossoides platessoides)

Long rough dab are abundant and widely distributed in the Barents Sea, as one of the most common groundfish species it plays an important role in the benthic community. Because it is not a commercial species, detailed information on the life history and ecology is lacking, and physical processes that influence the dynamics of this species are not well understood. Analyses of ichthyoplankton and bottom trawl surveys in the Barents Sea together with hydrographic information on water mass circulation and historical observations of spawning, bottom sediment classification and distribution of prey items provided the first comprehensive look at the life history and ecology of this species (Walsh 1996). Long rough dab are distributed from the coastal waters off western and northern Svalbard, south along the continental shelf edge to the northwest coast of Norway and eastward into the Barents Sea to

Goose Bank. The greatest concentrations are located within the Barents Sea. Both juvenile and adult long rough dab overlap considerably in their distribution and are most abundant along the shelves and slopes of various banks close to the Polar Front, in particular the slopes of Spitsbergen Bank. Analyses of icthyoplankton and demersal trawl survey data together with historical data and hydrography of water masses in the area suggest that spawning of long rough dab takes place mainly in the western and central Barents Sea and along the northwest coast of Norway, corroborating Milinsky's hypothesis of an east to west spawning migration. A spawning migration in the direction opposite to larval drift would permit long rough dab to maintain its position within the region, a strategy common to many other demersal and pelagic fish in the Barents Sea. The distribution pattern of newly-settled and age-1 juvenile long rough dab is closely linked to the physical oceanographic processes of water masses, in particular the North Atlantic water mass, and the drift of early life-history stages in the system of currents along coastal areas and the Polar Front. The association of large aggregations of juveniles with sediments of a particular structure and a high biomass of benthos may be more than coincidental and would indicate that other physical factors may influence both settlement in the oceanic nursery areas and the overall pattern of distribution of the population. For 2004-2005, the swept area abundance of long rough dab was estimated at 300,000 tons based on the ecosystem survey. This is probably a minimum estimate of stock abundance.

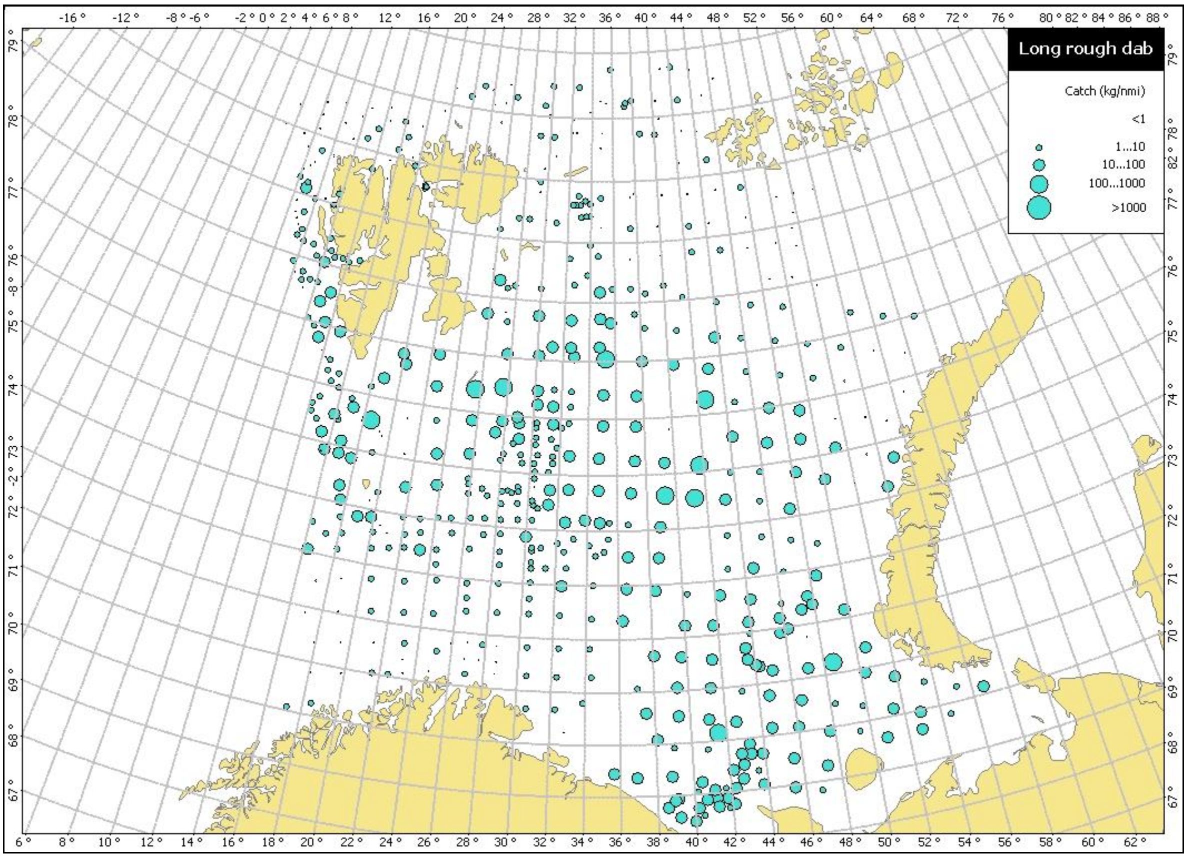


Figure 2.31. Distribution of long rough dab, from ecosystem survey in August-September 2007

2.4.6 Marine mammals

By M. Skern-Mauritzen (IMR), V. B. Zabavnikov (PINRO), S. V. Ziryanov (PINRO), N. Øien (IMR) and J. Aars (NPI)

2.4.6.1 General features

Approximately 25 species of marine mammals regularly occur in the Barents Sea: 7 species of pinnipeds (seals and walruses); 12 of large cetaceans; 5 of small cetaceans (porpoises and dolphins); and the polar bear (*Ursus maritimus*). Some of these are seasonal residents and have temperate mating, calving, and feeding areas in the Barents Sea (e.g. minke whale *Balaenoptera acutorostrata*). Others are year round residents (e.g. white-beaked dolphin *Lagenorhynchus albirostris,* and harbour porpoise *Phocoena phocoena*). Some marine mammals are rare; due either to natural life histories (e.g. beluga whale *Delphinapterus leucas*) or due to historic exploitation (e.g. bowhead whale *Balaena mysticetus*, and blue whale *Balaenoptera musculus*). Distributions of the most common marine mammal species are shown in Figure 2.32 - Figure 2.34. As top predors, marine mammals are critical components of marine ecosystems. Total annual food consumption by cetaceans in the world's marine ecosystems is estimated to represent 280-500 million tons (both vertebrates and invertebrates), which is 3 to 6 times greater than the total annual 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 are estimated to consume 1.8 million and 3-5 million tons of prey each year, respectively, including crustaceans, capelin, herring, polar cod, and gadoid fish species (Folkow *et al*. 2000; Nilssen *et al*. 2000). Relationships between marine mammals and their prey appear closely related to fluctuations in the marine systems. Both minke whales and harp seals are believed to switch between krill, capelin, and herring depending on prey availability (Lindstrøm *et al.* 1998; Haug *et al.* 1995; Nilssen *et al*. 2000; see also section 2.5.5). An added consideration is that marine mammals as commercial resources are prey species for humans, as both minke whales and harp seals are harvested. In recent years, Norwegian vessels have harvested approximately 600 minke whales annually from the North, Norwegain and Barents Seas. During 2007, 11 108 harp seals were harvested from ice areas in the White Sea and 7 828 harp seals were harvested from the drift ice outside east-Greenland (see Figure 2.34).

2.4.6.2 White-beaked dolphins (Lagenorhynchus albirostris)

White-beaked dolphins are the most numerous small cetacean. Their abundance in the northeast Atlantic has been estimated at 130,000 individuals (Øien 1996). They grow to nearly 3 m, and can weigh 300-350 kg. Little is known about their life history and reproduction. They are distributed in southern and central regions of the Barents Sea, and occur in groups ranging from 5-15 individuals, although larger groups may be encountered. In the western Barents Sea they typically inhabit areas south of the Polar Front, while in eastern areas they cross the Front to inhabit colder, arctic water masses (Figure 2.32). Some areas where they aggregate in the southern and western regions of the Barents Sea are rich in herring and blue whiting. However, their diet in the Barents Sea is unknown.

2.4.6.3 Harbour porpoise (Phocoena phocoena)

Approximately 80,000 harbour porpoises inhabit the north-east Atlantic (Bjørge and Øien 1995). Adults are 1.5 – 1.7 m long, and weigh 60-80 kg. Their life span can extend up to 24 years, and they become sexually mature at 3 – 4 years of age. After reaching maturity, females typically give birth annually to a single calf, which is nursed for 8-12 months. Harbour porpoises are solitary, coastal fish-eating mammals; they mainly prey on small pelagic fish. In the Barents Sea, they occur along the coast in the western region; in the eastern region they may inhabit banks distant from shore, e.g. Kanin and Goos banks (Figure 2.32). They are caught accidently in coastal gill-net fisheries; the extent of this by-catch is currently unknown.

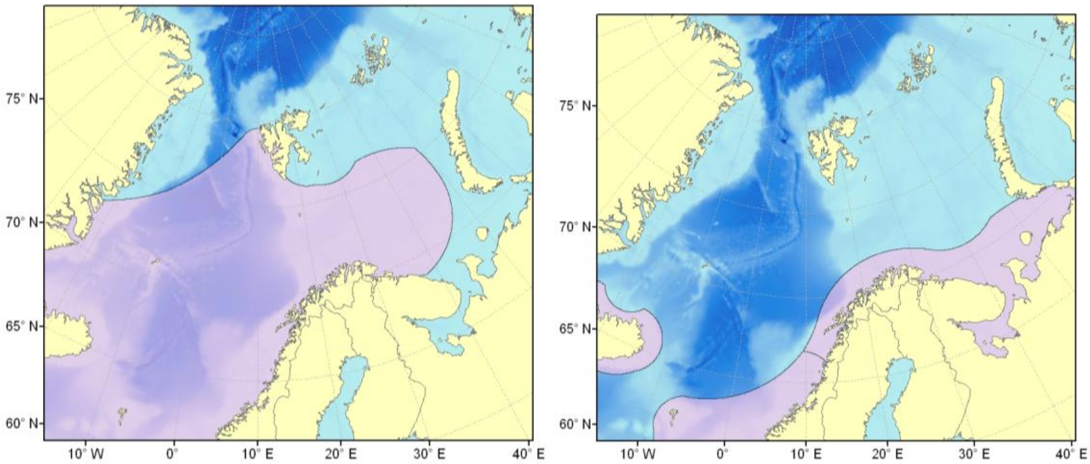


Figure 2.32. General distribution area for white-beaked dolphins (left panel) and for habour poise (right panel).

2.4.6.4 Minke whale (*Balaenoptera acutorostrata*)

Minke whales are the smallest of the baleen whales. In the north Atlantic they can reach 9 m in length, and weigh 5-8 tonnes. Although their age is difficult to determine, they may live up to 50 years. Mature females typically give birth annually to a single calf, which becomes weaned after 6 months. They are the most abundant baleen whale in the Barents Sea. The minke whale abundance in the North-East Atlantic was recently estimated to 103 462 individuals (cv. 0.16, Bøthun *et al*. 2008) which corresponds well with the previous abundance estimate from 2004 (107 205 individuals, Skaug et al. 2004) suggesting a rather stable minke whale population.

Minke whales are generalist predators; their diet strongly depends on feeding area and availability of prey species. Although they occur throughout the Barents Sea, highest abundance may occur in northern regions along the shelf edge, and in the southern region (Figure 2.33). In southern Barents Sea they feed on herring and krill, but seem to prefer summer spawning capelin (Smout and Lindstrøm 2007); in the north they feed on capelin, but may switch to krill when capelin abundance is low (Haug et al. 2002). During summer, they generally are abundant in southern and western regions; during late summer and autumn, however, they generally feed in northern regions (see Figure 2.43). Historic distribution data show large-scaled shifts in minke whale distribution in the Barents Sea, varying from extreme eastern (i.e. towards Novaya Zemlya) to extreme western distributions (i.e. along the shelf edge) — this was likely related to shifts in prey abundances (Eriksen 2006).

2.4.6.5 Humpback whales (*Megaptera novaeangliae*)

An estimated 1 200 (95% CI 700 – 2 000) humpback whales reside in the northeast Atlantic during summers (Øien 2003). Adults may reach 15-17 m in length, and weigh up to 40 tons. Their life expectancy is up to 50 years. Females give birth every 2-3 years to a single calf, which remains with its mother 1-2 years. Of all baleen whales, humpbacks have the most limited and conservative distributions within the Barents Sea. Their distribution is generally north of the Polar Front in western and central regions, although they may occur both in northern and southern regions (Figure 2.33). Their presence in these regions seems mostly related to concentrations of capelin and krill.

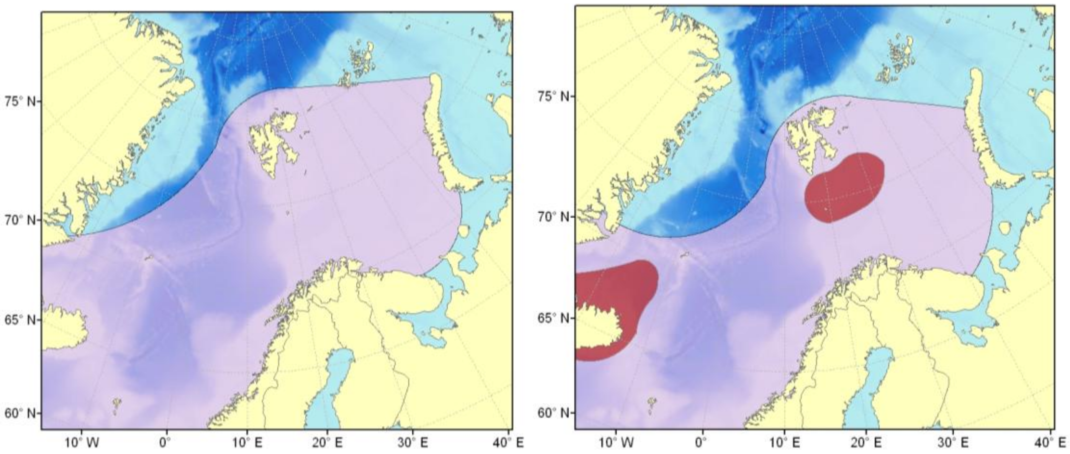


Figure 2.33. General distribution area for minke whale (left panel) and for humpback whale (right panel), with high density foraging areas (dark red) for humpback whale.

2.4.6.6 Fin whales (*Balaenoptera physalus*)

Fin whales are only second to blue whales in size. Adult fin whales may reach 23 m and 120 tons. Their abundance within the northeast Atlantic is estimated to be 5 400 individuals (95% CI 3 600 – 8 100, Øien 2003). Fin whales give birth to a single calf every 2 years, which stays with its mother 6-8 months. In the Barents Sea, fin whales generally inhabit deeper areas along the continental slope, west of Spitsbergen and in the Storfjorden trough. In recent years, however, fin whales have also been observed in the central and northern Barents Sea (Figure 2.34); thus expanding their general distribution area. Fin whales are found associated with zooplankton, pelagic fish, and 0 age-group fish (Mauritzen et al. in press). Although reasons for the expansion in range are not well understood, it could be linked to currently reduced abundance of zooplankton in the Norwegian Sea..

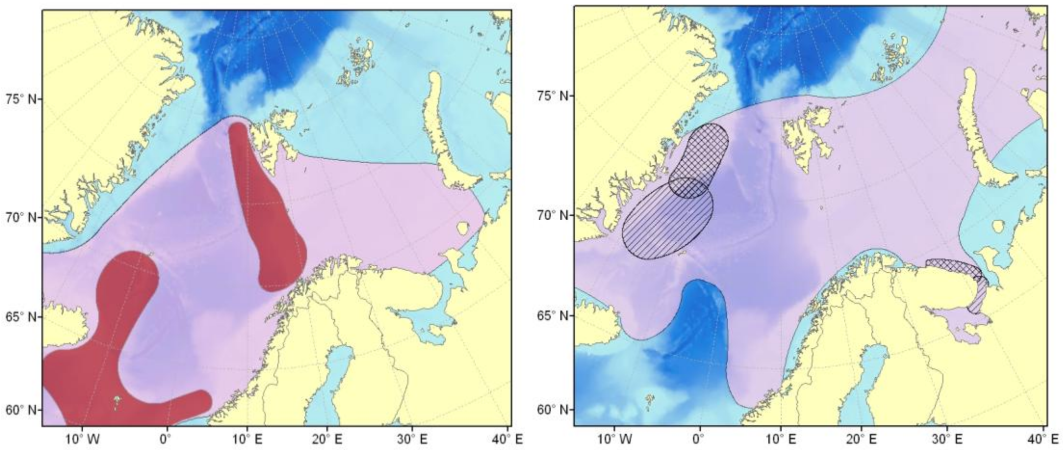


Figure 2.34. General distribution area (light red) and high density foraging areas (dark red) of fin whales (left panel) and distribution (light red) and whelping and moulting sites (cross-hatched) of harp seal (right panel).

2.4.6.7 Harp seals (Phoca groenlandica)

Estimated at over 2 million individuals, harp seals are the most numerous seal species in the Barents Sea. Two different stocks occur: the eastern stock (630,000 individuals) whelps and moults in ice along the East Greenland coast; the western stock (2.1 million individuals) whelps and moults on ice in and outside the White Sea (Figure 2.34). While the eastern stock migrates to the Barents Sea in July, and inhabits central and northern regions before returning to the eastern -ice in November-December; the western stock resides in the Barents Sea year around, and undertakes large, annual feeding migrations. Harp seals are generalist predators, and forage primarily on crustaceans and pelagic fish such as capelin and polar cod (see Table 2.4).

2.4.6.8 Polar bear (Ursus maritimus)

The Barents Sea polar bear is but one of 19 different populations in the Arctic. In 2004, the Barents Sea population was estimated to be 2 650 individuals (95% CI approximately 1 900 – 3 550), thus comprising 10 % of the total world population of polar bears. Polar bears inhabit drifting sea ice in the Barents Sea and fjords of surrounding archipelagos. They primarily hunt ringed-, harp-, and bearded seals. (Derocher et al. 2002). Between 1992 to 2002, the average age of polar bears in Svalbard increased (Derocher 2005, Christensen-Dahlsgaard et al. unpubl. data), while cub production per female decreased (Derocher 2005). Some of the decreased production may be due to reduced litter size in older females (unpublished data); some of the decrease may be explained environmentally, e.g. connected to climate change or population density (Derocher 2005). An analysis of population demography currently underway should provide new information that leads to update and extention of the time series.

2.4.7 Seabirds

By V. B. Zabavnikov (PINRO), M. Skern-Mauritzen (IMR), S. V. Ziryanov (PINRO) and N. Øien (IMR)

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 this region (Barrett *et al.,* 2002). Forty different species are believed to breed regularly around the northern part of the Norwegian Sea and in the Barents Sea. The most typical species belong to the auk and gull families. There are approximately 1,750,000 breeding pairs of Brünnich's guillemot (*Uria lomvia*) in this region; they feed on fish, particularly polar cod, and other ice-dwelling species. There are approximately 140,000 breeding pairs of common guillemots (*Uria aalge*); their most important year-round food source is capelin.

More than 1.3 million pairs of little auk (*Alle alle*) are believed to inhabit the Barents Sea. They occur throughout the region most of the year; many are believed to winter along the ice margin between Greenland and Svalbard, and in the Barents Sea. Small pelagic crustaceans are the principal food for this species; they also feed on small fish.

The black-legged kittiwake (*Rissa tridactyla*) breeds throughout Spitsbergen; similar to the Brünnich's guillemot, it is most common on Bear Island, Hopen, and around Storfjorden. Its most important food sources in the Barents Sea are capelin, polar cod, and crustaceans. There are an estimated 850 000 breeding pairs in the Barents Sea region; the population appears stable. The northern fulmar (*Fulmarus glacialis*) is an abundant Arctic and sub-Arctic species that lives far out at sea during all but breeding season. It feeds on plankton and small fish at the surface. Population estimates are uncertain, but large (100,000 – 1,000,000 pairs). The Atlantic puffin (*Fratercula arctica*) is the most abundant seabird on the mainland and in the Norwegian Sea; it also breeds on Bear Island and on Spitsbergen.

2.5 Ecological relations

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The ecosystem is a dynamic functional unit formed by the environment and by living organisms: plants, animals, microorganisms and human activities. The organisms in the ecosystem are linked, to form a food web. This food web has a trophic structure, and organisms within it can be grouped into trophic levels: producers (plants); primary consumers (feeding on the producers); secondary consumers (feeding on the primary consumers); etc. up to apex predators (i.e. predators at the top of the food web). Generally speaking, about 10% of energy in biomass consumed at one trophic level is transferred into biomass at the next trophic level. Therefore, total biomass at the lowest trophic levels is much larger than biomass at the highest trophic levels (Figure 2.35).

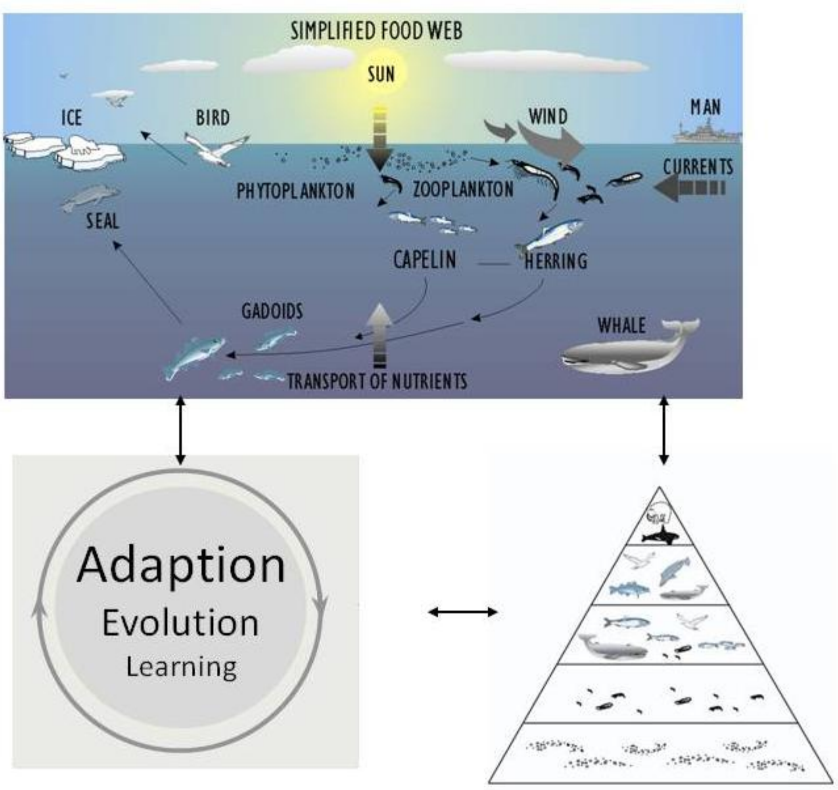

Figure 2.35. Central elements in marine ecosystem structure and functioning: interactions between organisms (top), the food web (bottom right), and the underlying evolutionary motivation (bottom left). (From Gjøsæter et al. 2008).

Trophic interactions are relations between species at different trophic levels. Organisms at different trophic levels influence each other through predation, whereas organisms at the same trophic levels influence each other through competition, since they feed on and compete for the same food sources. Predation and competition are important ecological processes linking organisms in the food web, but other processes — such as cannibalism, parasitism and mutualism — may also determine the food web and ecosystem dynamics.

In the Barents Sea ecosystem, trophic interactions between the major fish stocks, their predators, and their prey, are well understood through diet studies; the ecosystem's trophic structure is also quiet well understood. Pelagic fish species — that feed on zooplankton, but are prey to many species of larger fish, mammals, and birds — form an intermediate trophic level. It has been suggested that the trophic structure of the Barents Sea ecosystem is a 'wasp-waist' system: pelagic fish at the intermediate trophic level (particularly capelin) determine energy flux — from the lowest to the highest trophic levels — by regulating zooplankton through grazing they control the biomass available to apex predators. Therefore, dynamics of the capelin stock determine, to a large extent, dynamics and trophic structure of the Barents Sea ecosystem. Dynamics of the capelin are, in turn, determined by trophic interactions with cod and herring, and the sizes of all three stocks; juvenile herring prey on capelin larvae, and cod consume adult capelin. Sizes of herring and cod stocks are largely influenced by environmental factors; strong year classes for both cod and herring ocur during years with high inflow of Atlantic water. Size of the capelin stock has varied widely since the early 1980's, and Barents Sea ecosystem dynamics during the last 25 years can be described by contrasting the trophic structure between years with high or low capelin abundance.

Cod is a major predator in the Barents Sea ecosystem. Growth patterns of young Northeast Arctic cod in the Barents Sea have strong fluctuations. The mean length of age 3 cod, sampled in the Norwegian winter bottom trawl survey, has varied between 28 and 42 cm during 1984-2007 (ICES, 2007); correspondingly, the mean weight at age 3 has varied between 200 and 800 g. Thus, predictions of cod stock biomass must incorporate predictions of size at age as well as abundance at age. Strong trophic relationships between cod, capelin, and euphausiids have been documented e.g. by Drobysheva and Yaragina (1990). Cod predation on euphausiids decreased the food supply for capelin; reduced capelin feeding reduced potential for capelin stock recovery. Concurrently, capelin predation on euphausiids reduced the food supply for both juvenile and adult cod. Individual fish growth depends on density- dependent factors such as prey availability; growth also depends on biological processes (feeding, metabolism, excretion etc.) that are influenced by temperature (Ottersen *et al*. 2002; Michalsen *et al.* 1998).

The biomass and abundance of major fish species indicates their importance to ecosystem functioning, and their influence on key processes determining dynamics of the Barents Sea ecosystem. Many ecological relationships, however, require better understanding — processes related to competition, parasitism, and mutualism — before their status can be assessed. Similarly, relatively little is understood about dynamics of the microbial loop, or trophic interactions of important species groups such as detritus feeders (e.g. shrimp, and many other benthic species), and less-abundant fish species.

2.5.1 Marine ecosystem responses to climate variability

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

With warming during the 1920s and 1930s, cod occured in high abundance on Bear Island Bank; as result the cod fishery there was reestablished after an absence of almost 40 years (Blacker, 1957). Cod also spread northward into the area off West Svalbard in sufficient abundance to support a fishery (Beverton and Lee, 1965). Cod, as well as haddock, moved eastward to reach Novaya Zemlya archipelago by 1929-1930 (Cushing, 1982). There was a shift in spawning distribution, with proportionately more cod spawning in northern regions of Norway (Lofoten and Finnmark) than in southern Norway at Møre (Sundby and Nakken, 2004). During colder periods before and after the warm period, the proportion of cod spawning at Møre was much higher. Cod might also have spawned earlier during the warm period, based upon time-based ratios of the weight of cod roe to weight of the cod at Lofoten, (Pedersen, 1984). Younger cod spawn later (Pedersen 1984); delayed spawning during cold periods might could result from having fished down the population of older cod.

Sizes of Arcto-Norwegian cod stocks in the Barents Sea and off Norway's coast peaked in the 1930s and 1940s (Hylen, 2002). Consistent with increased levls of abundance at that time, catch-per-unit-effort (CPUE) also was significantly higher during the period 1925-1960 than during periods before or since (Godø, 2003). While this change coincided with rapid growth of the trawl fishing industry and increased fishing efficiency, higher recruitment during the warm period cannot be ruled out as a contributor to the increased CPUE (Godø, 2003). High recruitment is believed to a result of greater food availability (Sætersdal and Loeng, 1987; Ottersen and Loeng, 2000). Mean weight of cod in Lofoten cod rose rapidly during the 1920s and early 1930s, and remained high before a general period of decline began in the 1960s; mean weight increased over 50% between the pre-1920s period and the 1930s-1960s period.

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

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

2.5.2 Plankton and fish

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

2.5.2.1 Zooplankton-capelin

Capelin is one of the main components in the transfer of trophic energy from lower to higher trophic levels in the Barents Sea ecosystem. From the early 1980s till today the capelin stock has fluctuated significantly, and it is interesting to observe the importance of this variability for the measured zooplankton stock in August-September throughout the same period. Even if many factors influence the abundance and zooplankton production, it seems to be close to an inverse relationship between capelin and zooplankton biomass (Figure 2.36). When the capelin stock was at a minimum in 1994-1995, a maximum in zooplankton abundance was observed.

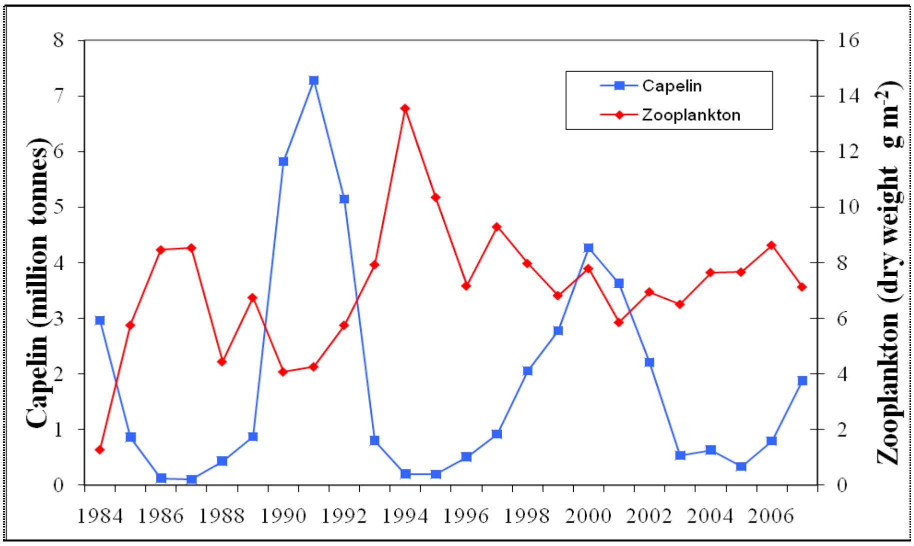

Figure 2.36. Annual fluctuations in zooplankton biomass (Norwegian data) and size of capelin stock in the Barents Sea.

Capelin stomachs were sampled both by Norwegian and Russian vessels during the ecosystem cruises in 2005-2007 in autumn (August-September). For each station, the mean Partial Fullness Index (PFI) and Total Fullness Index (TFI) (Table 3.3 in section 3.4) were calculated to permit comparison of quantities of various prey groups in the stomachs of predators of various sizes (see e.g. the survey report Vol. II (Anon. 2007 and 2008) for definitions of PFI and TFI). The PFI and TFI by prey species group was then averaged over all fish sampled within each single station.

Here mainly data from 2006 are shown, though some results on the capelin diet in 2005 are also provided for comparison. The analysis of the 2007 data has not been completed. According to the results of the ecosystem survey in 2006 (Anon., 2007), the main concentrations of capelin were distributed between 74º40'-77º20'N and 26º-42ºE. The northern boundary of aggregations reached 80ºN to the west and east of Spitsbergen; to the south of 76ºN, mainly small immature fish were found. The areas of basic capelin concentrations and feeding mainly coincided (Figure 2.37). During August-October, the feeding areas of mature and immature capelin (8.5-18.5cm) were in the northwestern and central areas of the Barents Sea, whereas exclusively large mature capelin (13-19 cm) were observed in the east.

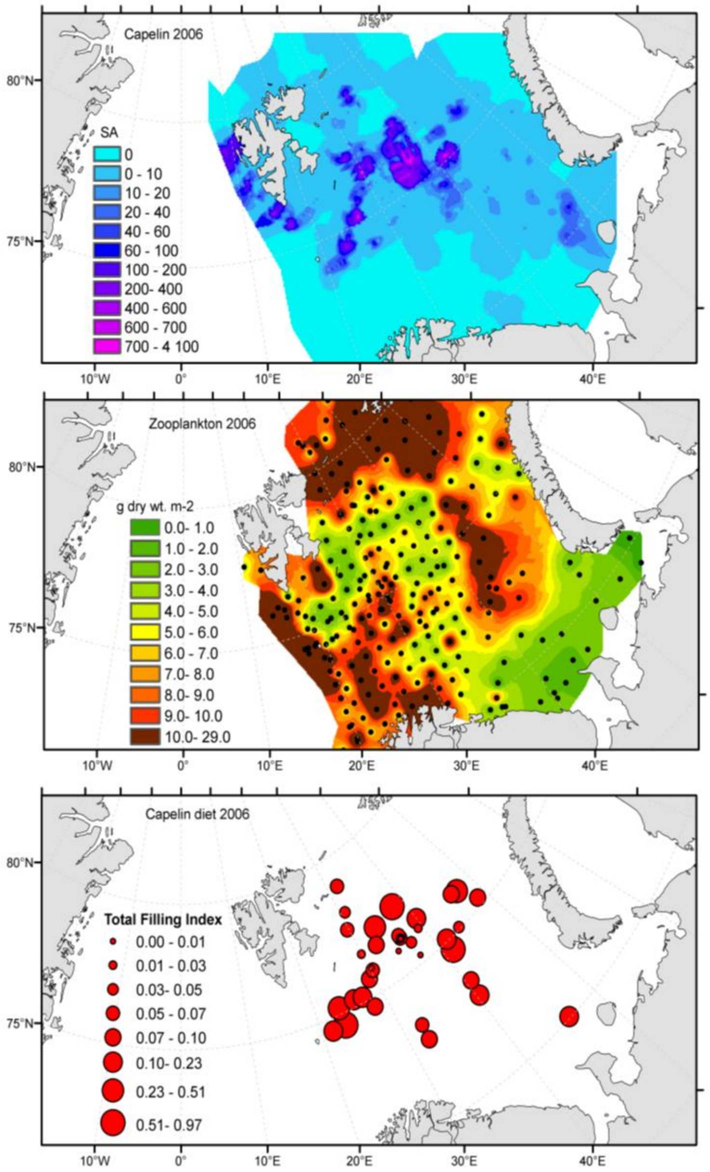

Figure 2.37. Distribution of capelin Sa values (Anon. 2006), zooplankton, and capelin stomach content expressed as Total Fullness Index (TFI – dry weight) from 2006.

Long term studies of predator-prey interactions between capelin and zooplankton reveal that there is a significant inverse relationship between capelin and zooplankton in the Barents Sea and that predation pressure on zooplankton by capelin is a main factor regulating the zooplankton biomass. Figure 2.37 shows that the areas of high densities of capelin (high Sa values) and high TFI are reflected by low densities of zooplankton. Capelin seems to feed more intensively in the north-west and central parts of the Barents Sea. Some important feeding areas in 2006 seem to be the eastern slope of the Bear Island Bank, and areas of the Spitsbergen Bank where high TFI values up to 0.97 were recorded.

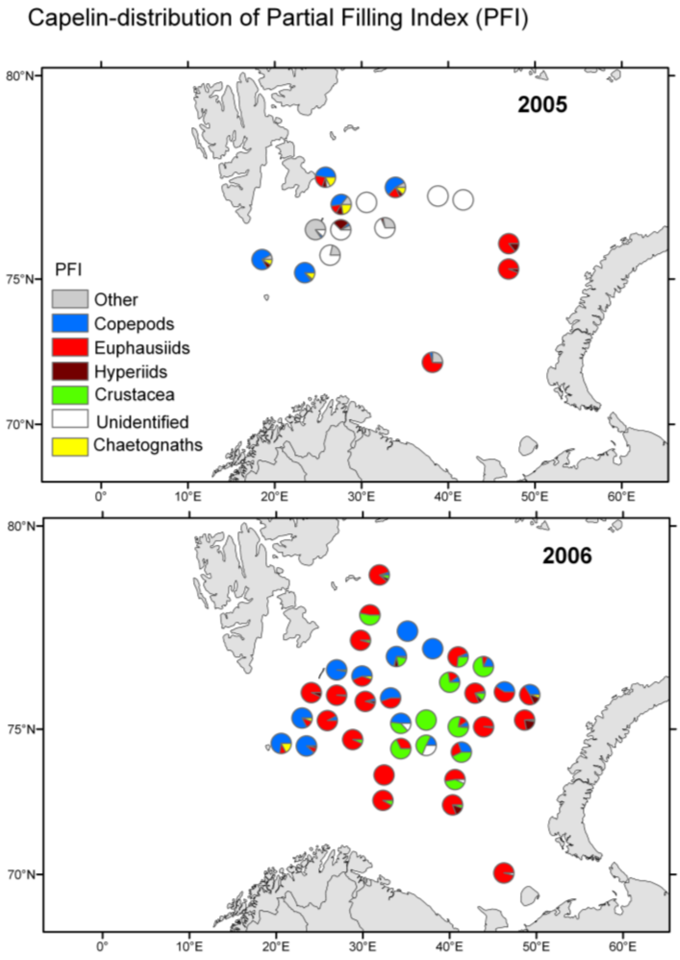

Figure 2.38. Diet composition, measured as Partial Fullness Index (PFI) in capelin stomachs, from 2005 and 2006.

Copepods and euphausiids seem to dominate the diet of capelin in 2005 and 2006. Euphausiids seems to be most important in the south and eastern part of the Barents Sea. *T. inermis* was by far the most dominant euphausiid species, though *T. longicaudata* and *M. norvegica* were occasionally present. Capelin fed more intensively in the north-west and in some stations copepods contributed largely to the diet of capelin. Copepods often consisted of a mixture of the species *C. finmarchicus*, *C. glacialis* and *C. hyperboreus*, and *M. longa*. In the colder waters, in general, *C. glacialis* was dominant over *C. finmarchicus* in the diet. Mostly, large copepods (stage V) and females made up the bulk of the copepods in the diet. In addition, hyperiids (*Themisto* spp.) and chaetognaths were important in some stations in the eastern and western part of the Barents Sea respectively. Table 2.2 and Table 2.3, from 2005 and 2006, respectively, summarize the food composition of capelin expressed as a percentage of the total stomach content weight (wet weight) for different size classes of capelin. These results show that in both years, the smallest capelin (<11cm) fed almost exclusively on copepods, while in the larger ones

(>11 cm), the proportion of krill increased in their diet. In addition, in the larger capelin, hyperiids and chaetognaths were also important components of the diet in 2005 and 2006.

Table 2.2. Food composition of capelin during August-October 2005, % by total stomach content wet weight (TFI is in dry weight)

Prey species	Capelin size, cm					Total
	9.1-11.0	11.1-13.0	13.1-15.0	15.1-17.0	17.1-19.0	
Euphausiids	1.25	20.74	16.25	37.26	21.65	19.43
Hyperiids	0	0.69	4.58	9.17	1.24	3.13
Copepods	72.52	59.39	56.66	44.09	38.28	54.19
Chaetognaths	7.43	17.66	15.45	8.90	38.82	17.65
Other food	18.80	1.52	7.07	0.58	0.00	5.59
Number of stomachs	33	43	97	73	4	250
Empty stomachs, %	33.3	9.3	6.2	9.6	0	11.2
Mean fullness index, ‱	41.17	346.41	285.56	205.39	368.45	285.17
TFI	0.032	0.313	0.289	0.222	0.349	0.239
Mean weight of capelin (g)	3.83	8.61	14.63	21.70	25.62	14.88

Table 2.3. Food composition of capelin during August-September 2006, % by total stomach content wet weigh t(TFI is in dry weight)

Prey species	Capelin size, cm					Total
	9.1-11.0	11.1-13.0	13.1-15.0	15.1-17.0	17.1-19.0	
Euphausiids	29.00	36.66	31.19	36.58	24.40	31.57
Hyperiids	0.36	0.27	1.75	4.94	4.36	2.33
Copepods	69.46	59.20	61.17	56.44	69.98	63.25
Chaetognaths	0.24	3.59	2.69	1.71	0.06	1.66
Other food	0.94	0.28	3.20	0.33	1.20	1.19
Number of stomachs	60	120	124	184	43	531
Empty stomachs, %	33.3	21.7	22.6	20.1	23.3	22.7
Mean fullness index, ‱	77.11	171.35	222.33	230.84	214.62	208.84
TFI	0.061	0.143	0.224	0.251	0.246	0.198
Mean weight of capelin (g)	4.61	6.97	14.52	22.39	31.14	15.92

2.5.3 Benthos and fish

Bottom animals make up parts of, or the total diet, of several fish species. The last 20 years has been subject to an extended sampling of stomachs from cod and haddock (Jiang and Jørgensen, 1996). Preliminary evaluation of these data shows 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 2.39). 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. The diet of cod (7-11 years old) when eating bottom animals (less that 10 % of total stomach content) varies little with area (Figure 2.41) and constitute mainly of crustaceans such as Spirontocaris spinus (prawn) and Hyas spp. (decorator crabs), while in the northern areas the amphipods Tmetonyx (amphipod) while Pagurus bernhardus in the eastern and western areas functions as an additional prey species.

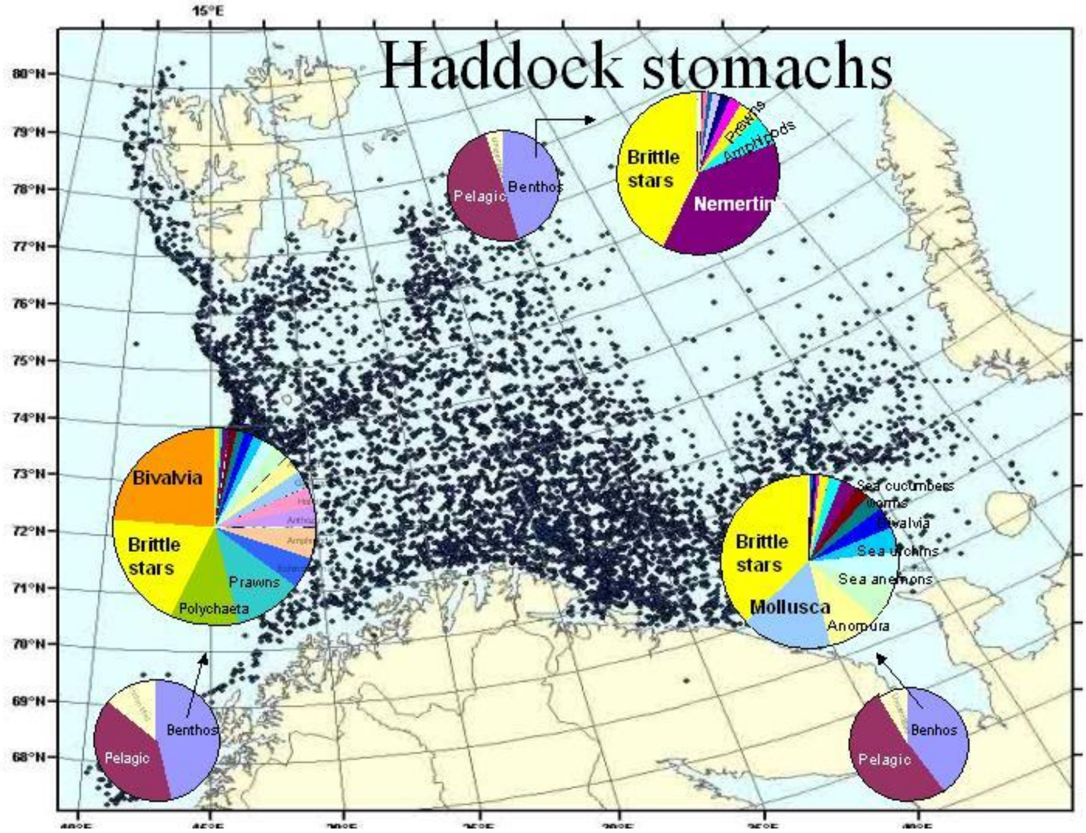

Figure 2.39. The stomach content (small reddish blue circles) of haddock (3-11 years old) and detailed information (yellow orange circles) on what animal groups (approximately 50% of the total stomach content) that constitute bottom species.

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

Deep sea shrimp (*Pandalus borealis)* is an important prey for several fish species, especially cod, but also other fish stocks like blue whiting (ICES, 2007). Consumption by cod has been estimated to be 5 times the catches of shrimps. It is therefore obvious that cod can have a significant influence on shrimp population dynamics and stock size. If predation on shrimp were to increase rapidly outside the range previously experienced by the shrimp stock within the modelled period (1970–2007), the shrimp stock might decrease in size more than the model results have indicated as likely. However, as the total predation depends on the abundance both of cod and also of other prey species the likelihood of such large reductions is at present hard to quantify.

2.5.4 Predation by fish

2.5.4.1 Cod diet

The diet of cod is a good indicator of the state of the Barents Sea ecosystem. Figure 2.40 shows the diet of cod in the period 1984-2007, calculated from data on stomach content, gastric evacuation rate and number of cod by age. The consumption calculations show that the total consumption by cod in the last years has been 4-5 million tonnes. The consumption per cod for the various age groups has also been fairly stable. Capelin was also in 2007 the most important prey item for cod, followed by krill, haddock, shrimp, hyperiid amphipods, herring, blue whiting, polar cod and cod. The proportion of capelin in the diet of cod has been about 30% in 2004-2007. Cod cannibalism is now at a low level, while the consumption of haddock by cod is at a record high level. There is a good correlation between prey availability and prey selection (i. e. stomach content) in cod. This can be seen both from the geographical and inter-annual variation in cod diet. The mature cod migrates out of the Barents Sea and spawns in the Lofoten area in March-April. The consumption rate by mature cod during this period is lower than during the rest of the year, with the main prey items being adult herring and Norway pout (Michalsen et al. 2008).

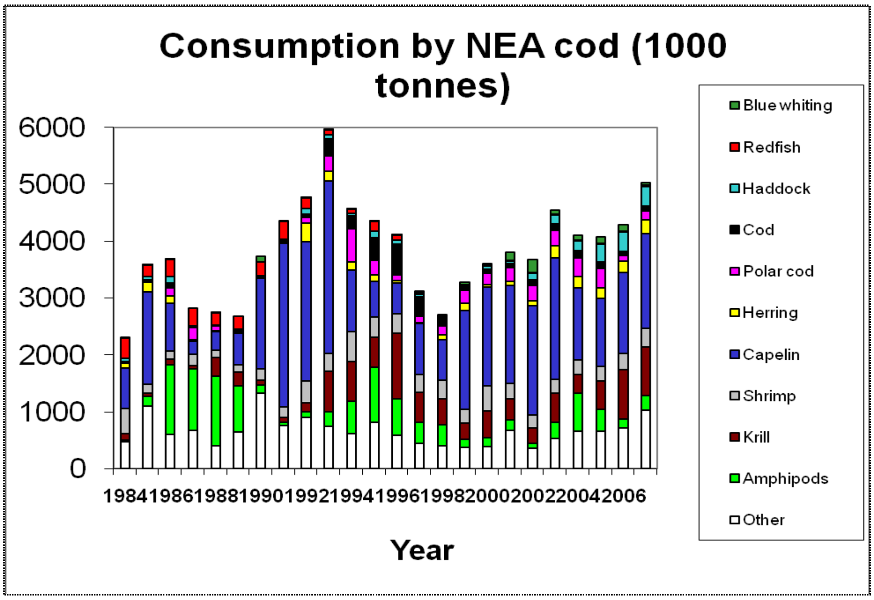

Figure 2.40. Consumption by Northeast Arctic cod in the period 1984-2007.

Stomach content analyses showed that the 0 and 1 group cod fed mainly on crustaceans with krill and hyperiid amphipods comprising up to 70% of their diet. Krill (*Thysanoessa* spp. and *M. norvegica*) and hyperiid amphipods (*Themisto* spp.) were mainly found in cod stomachs sampled in the central and close to the Polar Front region in the Barents Sea where these prey organisms are reported to be abundant in summer.

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

For cod age 3-6, the diet composition during the ecosystem survey 2007 was very variable between the areas, reflecting the difference in geographical distribution of the various prey items. In general shrimp, fish (mostly capelin, haddock, herring and polar cod) dominated in the cod diet. Fish including blue whiting and herring was the dominant prey item in the south-western part, while shrimp, herring, haddock, krill, and capelin dominated in the south-eastern part. In the central Barents Sea shrimp and capelin were the most important prey in a large area, while capelin and polar cod dominated near Novaya Zemlya and in the northern part.

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

2.5.4.2 Blue whiting

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

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

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

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

2.5.4.3 Other fish 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.

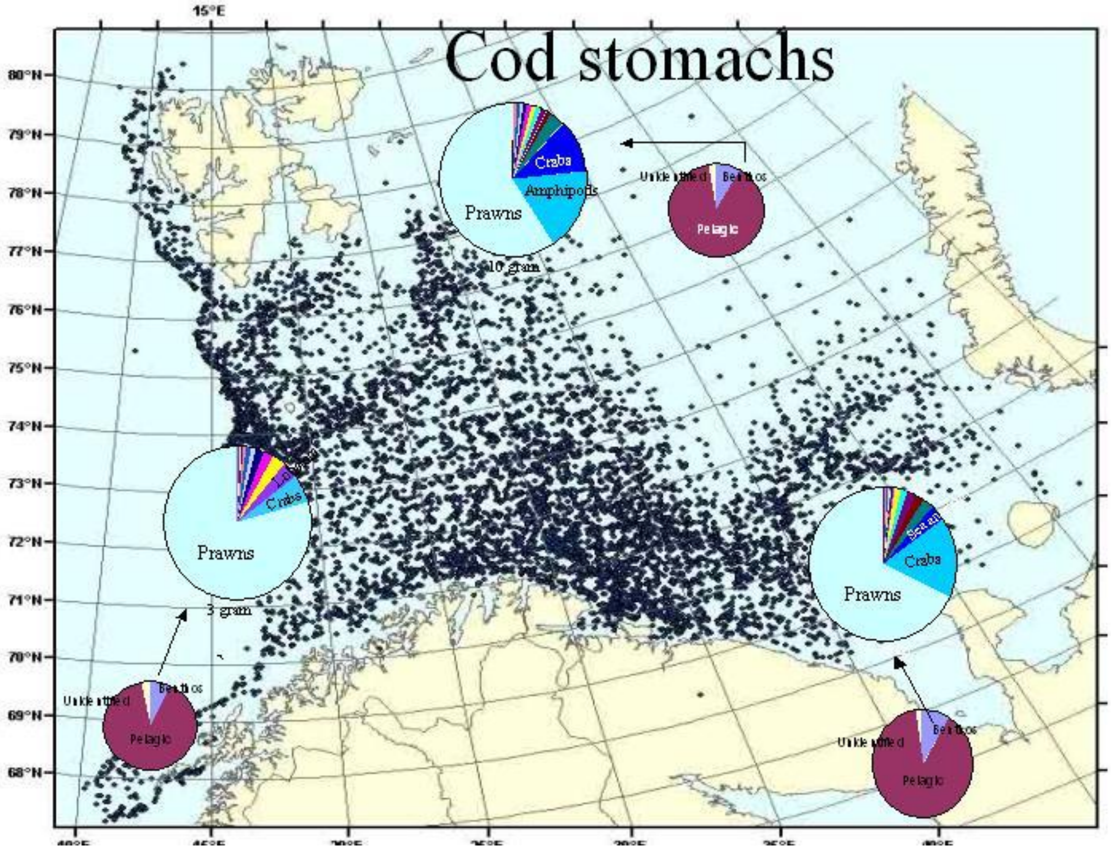

Figure 2.41. The stomach content (small reddish circles) of cod (7-11 years old) and detailed information (large bluish circles) on what animal groups (less that 10 % of total stomach content) that constitute bottom species.

2.5.5 Predation by mammals

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

Consumption estimates by minke whales (Folkow *et al.* 2000) and harp seals (Nilssen *et al.*, 2000) are given in Table 2.4. These estimates are based on stock size estimates of 85 000 minke whales in the Barents Sea and Norwegian coastal waters (Schweder *et al*., 1997) and of 2 223 000 harp seals in the Barents Sea (ICES 1999/ACFM:7). The consumption by harp seal is calculated for situations with both a large and a small capelin stock, while the consumption by minke whales is calculated for a situation with a large herring stock and a small capelin stock. Food consumption by harp seals and minke whales combined is at about the same level as the food consumption by cod. Thus, the predation by these two species needs to be considered when calculating the mortality of capelin and young herring in the Barents Sea. However, as can be seen from the harp seal consumption estimates in Table 2.4, the dietary importance of the different prey species depends highly on the prey species' availability. Such variation in diet due to variation in availability of prey species also applies to minke whales. In the period 1992-1999, the mean annual consumption of immature herring by minke whales in the southern Barents Sea varied considerably (640 t –118 000 t) (Lindstrøm *et al.,* 2002). The major part of the consumed herring belonged to the strong 1991 and 1992 year classes and there was a substantial reduction in the dietary importance of herring to whales after 1995, when a major part of both the 1991 and 1992 year classes migrated out of the Barents Sea and into the Norwegian Sea. This in turn likely reduced the role of herring as prey in the Barents Sea, which is reflected by a more northern minke whale distribution in 1995 compared to earlier years (Eriksen 2006). On the other hand, the importance of herring as prey likely increased in the Norwegian Sea in 1995, where minke whales seemed to track the migrating herring towards the polar front, thus reducing the role of shelf feeding observed in minke whales prior to 1995 (Eriksen 2006). The dietary importance of herring to minke whales appeared to increase in a non-linear relation with herring abundance, indicating that minke whales switch to alternative prey species when herring abundance decreases below a certain level (Lindstrøm *et al.* 2002).

The diet of marine mammals also varies through the season, depending on where they are foraging. While most of the cetaceans leave the Barents Sea in autumn, harps seals may spend the entire year within the Barents Sea. The seals breed and moult in the White Sea in spring, and perform extensive migrations covering large parts of the Barents Sea during summer, autumn and winter. In spring, when migrating through the southern Barents Sea, the diet predominantly consists of fish, such as herring and cod. Through the summer, they migrate northwards, and the diet switch to polar cod and krill, and in the autumn to amphipods and capelin (Figure 2.42, Lindstrøm et al. 2006). However, in both study periods when the summer diet was sampled (1996/1997 and 2004/2005) the capelin stock was at a very low level. This may certainly have influenced the observed seal diets, and so far no summer samples are available in periods with high capelin abundance in the Barents Sea.

Table 2.4. Annual consumption by minke whale and harp seal (thousand tonnes). The figures for minke whales are based on data from 1992-1995, while the figures for harp seals are based on data for 1990-1996

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

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

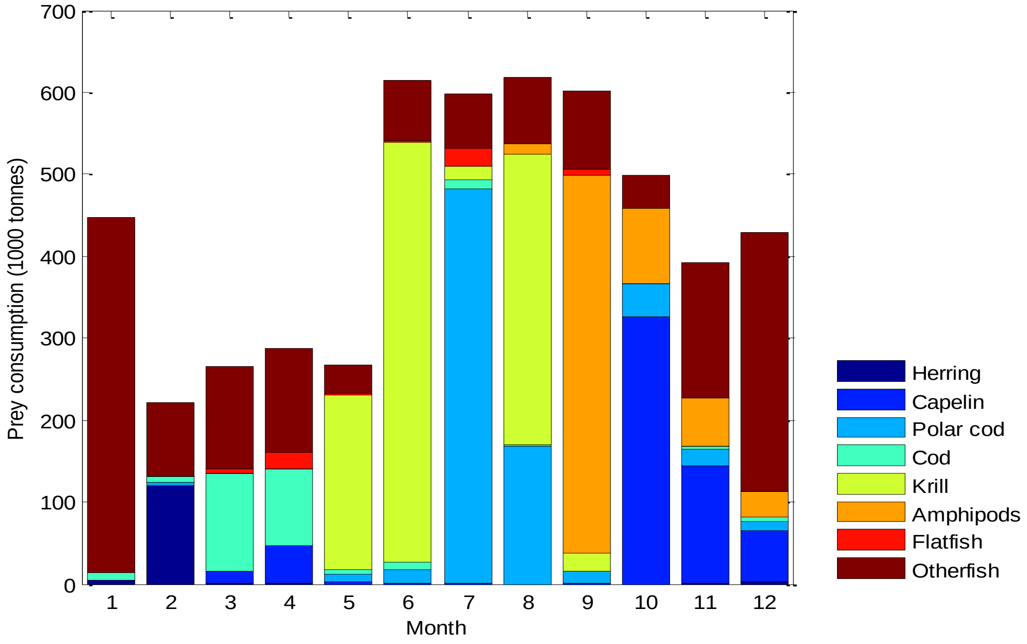

Figure 2.42. Monthly variation in harp seal consumption through the year.

In August-September 2003-2007 information on spatial distribution of marine mammals relative to prey distributions were collected during the ecosystem cruises. The main baleen whale species; minke, fin and humpback whales, were predominantly observed in Arctic water masses north of the polar front (Figure 2.43A). The most abundant toothed whale, the white-beaked dolphins, primarily inhabited the southern and central Barents Sea, but also they were crossing the polar front (Figure 2.43B). While the capelin, still at a low abundance level, was distributed in the central Barents Sea, abundant herring and blue whiting stocks were distributed in the southern Barents Sea and an abundant polar cod stock in the northern Barents Sea (Figure 2.44).

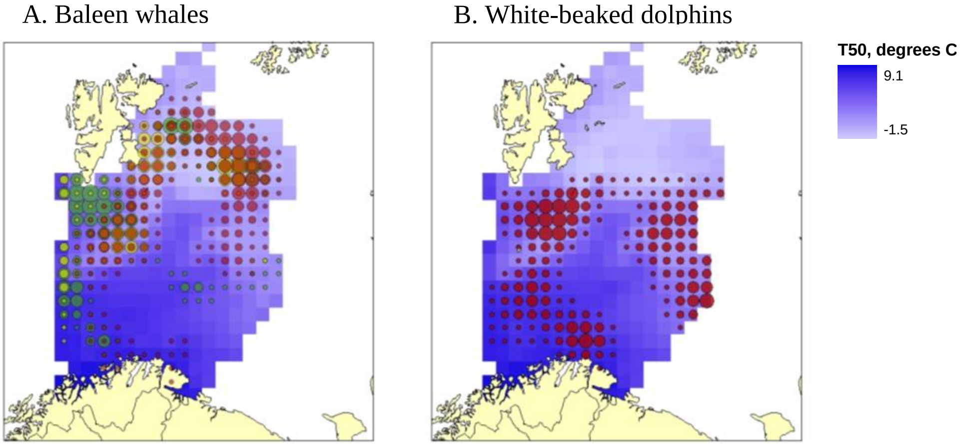

Figure 2.43. Modelled mean distribution of minke (red dots), fin (blue dots) and humpback whales (yellow dots, A) and white-beaked dolphins (red dots, B) as observed during ecosystem cruises in August-September 2003-2007, relative to water temperature at 50 m (blue shadings). Increasing dot sizes reflects increasing whale densities.

The northern baleen whales were typically aggregating at the rim of the capelin and polar cod distributions (Figure 2.44), apparently avoiding areas where pelagic fish were abundant (Figure 2.44). This implies that the baleen whales, at least this time of year, primarily forage on other prey than pelagic fish, possibly as a response to the low capelin abundance. Baleen whales, as skimmers or lunge feeders, are dependent on a certain prey density to forage efficiently (Piatt and Methven 1992). Analyses of cod stomachs show that cod is primarily foraging on amphipods in these northern areas (Johannesen pers. com.), and amphipods may very well be the primary prey also for baleen whales in this area. Furthermore, aggregating at the rim of the pelagic fish distributions also suggests that i) baleen whales avoid the areas with highest pelagic fish densities, possibly due to prey depletion in these areas, and ii) that baleen whales and pelagic fish are foraging on similar prey. In that case, pelagic fish in Arctic waters compete with whales for food, and this competition structure the spatial distribution of whales. In the south, both fin and minke whales aggregated at high herring and blue whiting densities, indicating that pelagic fish is preyed upon in this area. Nevertheless, the low density of baleen whales in southern Barents Sea suggests that the abundant southern pelagic fish stocks experience low predation pressure by baleen whales. These findings are thus contrasting results from studies of whale – fish interactions in previous periods with low capelin abundance, as herring appeared to be an important alternative prey species (see above, Lindstrøm *et al.* 2002). However, during the last years, the abundance of zooplankton in northern areas seems to be sufficient to feed the baleen whales. The most abundant dolphin in the Barents Sea, the white-beaked dolphin, was distributed in southern and central Barents Sea (Figure 2.44). The white-beaked dolphins are fish-eaters, and aggregated partly in areas with abundant herring and blue whiting, and partly in eastern Barents Sea outside the main distribution areas for pelagic fish. Thus, white-beaked dolphins likely forage on bottom-dwelling species, or possibly on squid, in the eastern Barents Sea.

Capelin abundance is currently increasing in the Barents Sea. This increase may either lead to intensified competition between capelin and baleen whales in northern arctic waters, which in turn may result in increased whale densities in the southern parts of the Barents Sea. Alternatively, the whales may switch to forage on capelin, as they can forage efficiently on capelin when densities are sufficiently high (Piatt and Methven 1992). Thus, by collecting such synoptic, spatial data for another couple of years, we will likely have sufficient information to show how fluctuations in the capelin stock affect the trophic links between marine mammals and the different prey species in the Barents Sea.

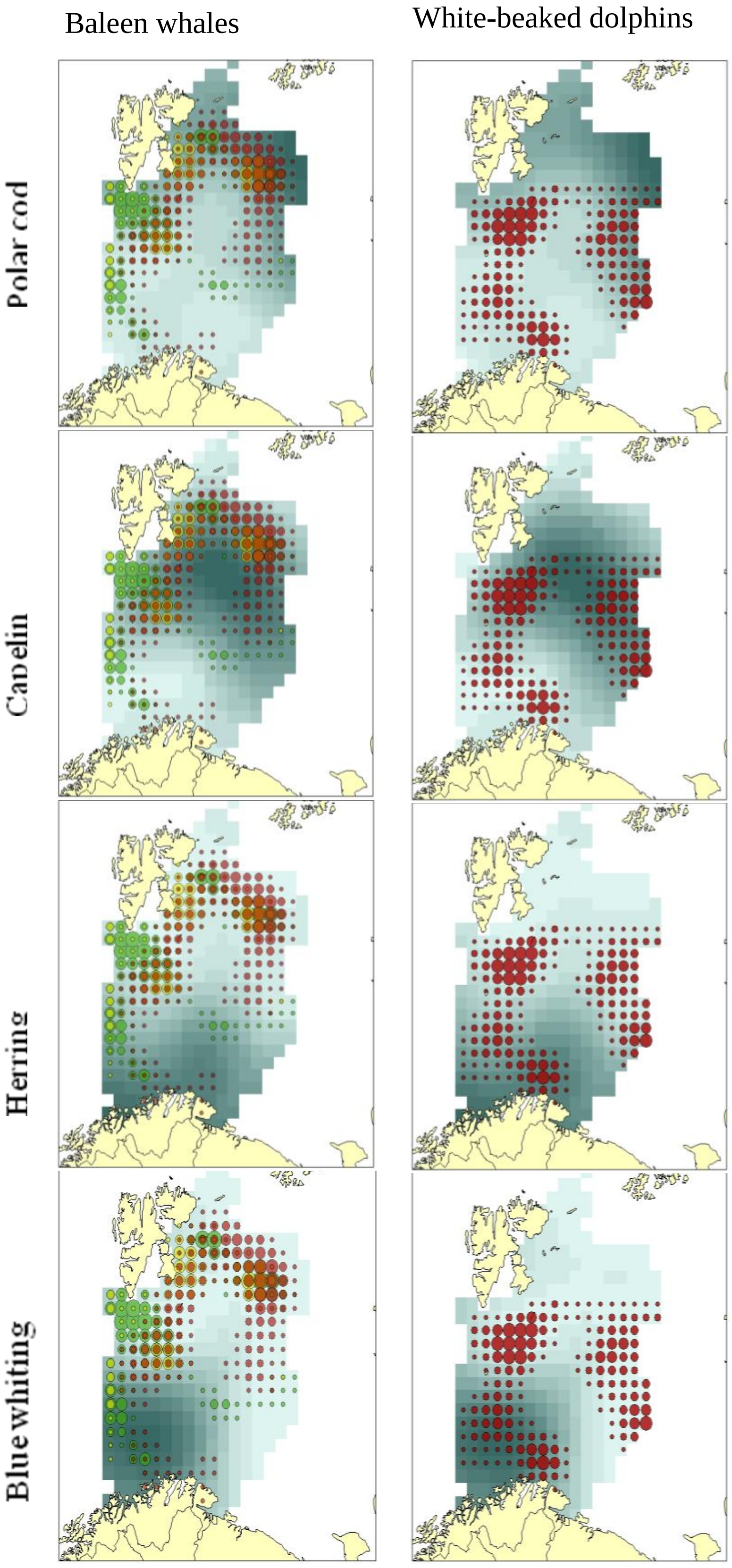

Figure 2.44. Modelled mean distribution of minke (red dots), fin (blue dots) and humpback whales (yellow dots, left panels) and white-beaked dolphins (red dots, right panels) as observed during ecosystem cruises August-September 2003-2007, relative to modeled mean distributions of polar cod, capelin, herring and blue whiting for the same period (green shadings). Increasing dot sizes reflects increasing whale densities, and darker green colors reflect increasing fish densities.

2.5.6 Present indications of an ecosystem regime shift ?

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

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

Figure 2.44 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 seems to be no sign of an irreversible regime shift or strong steady change in the ecosystem as a whole. However, the future climate scenarios given by the recent IPCC report (IPCC, 2007) give in most of the cases a temperature regime that is much higher than previously observed in the Barents Sea. That means that one of the major ecosystem driving mechanisms moves into a range in which we have little knowledge on how the ecosystem as a whole will respond. In that sense a regime shift in the future cannot be ruled out.

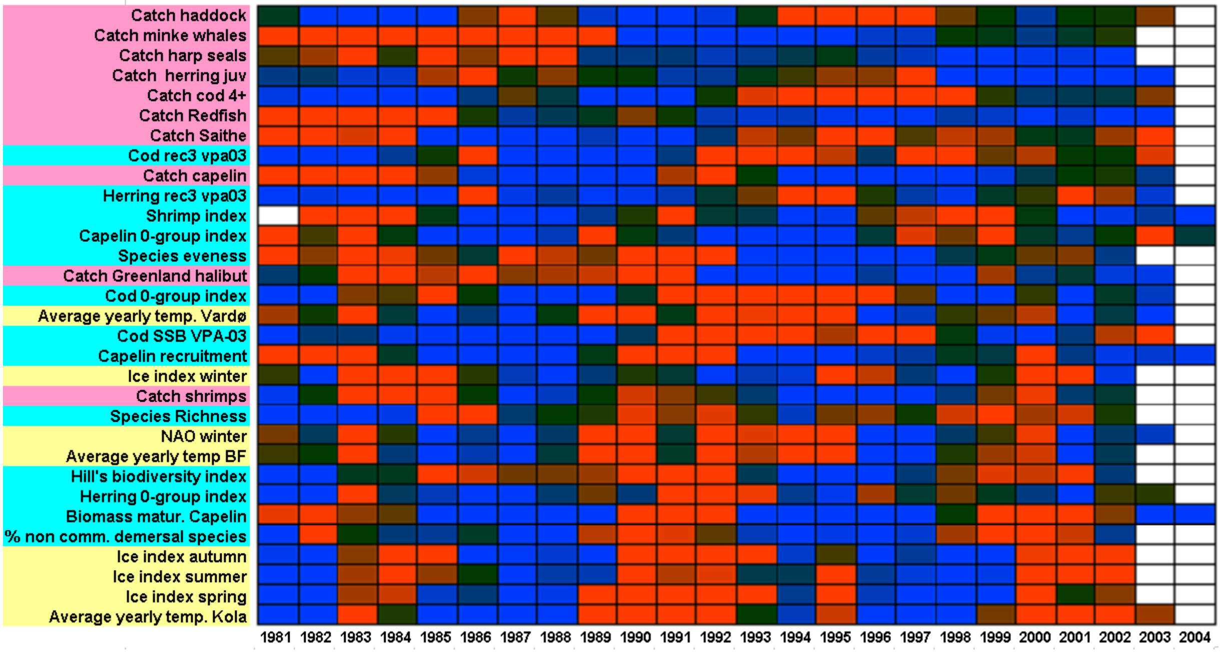

Figure 2.44. Normalized time series from the Barents Sea Ecosystem 1981 to 2004. Blue color is negative deviation and red colour is positive deviations. The colouring of the names on the left side reflect type of time series; Red is catch, yellow is climate and green is other biological time series.

3 Monitoring of the ecosystem

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Monitoring of the Barents Sea started already in 1900 (initiated by Nikolay Knipovich), with regular measurement of temperature in the Kola section. In the last 50 years monitoring of ecosystem components in the Barents Sea on a regular basis have been conducted by PINRO and IMR at several standard sections and fixed stations as well as by area covering surveys. In addition there are conducted many long and short time special investigations, designed to study specific processes or knowledge gaps. Also the quality of large hydrodynamical numeric models is now at a level where they are useful for filling observation gaps in time and space for some parameters. Satellite data and hindcast global reanalysed datasets are also useful information sources.

3.1 Standard sections and fixed stations

In order to ensure the comparability of observation results and to estimate seasonal and year-to year variations in oceanographic variables, it was suggested in Stockholm as early as 1899 that measurements should be made at standard depths and on standard sections. At the beginning of the 20-th century observations commenced on the Kola Section in the Barents Sea (Knipovich 1906), and by the 1930s, a network of such sections had been developed in the area (Figure 3.1). 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.

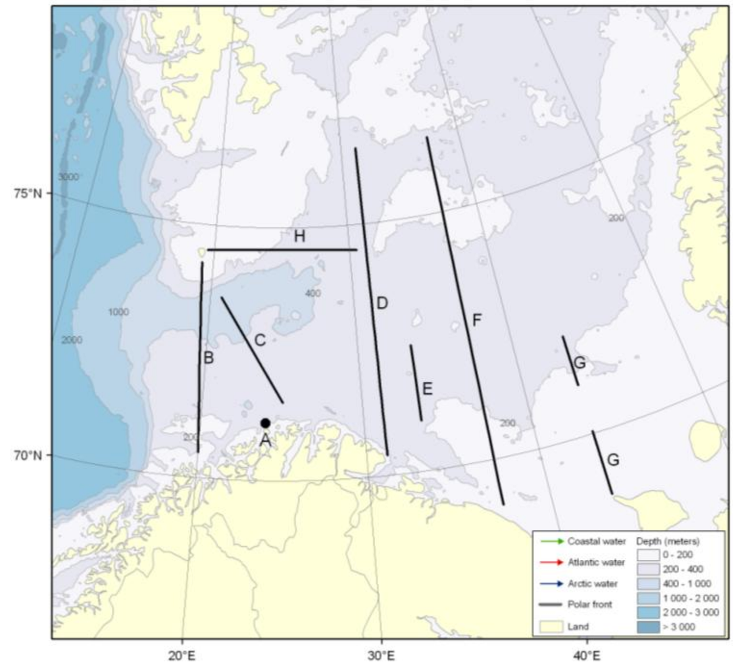

Figure 3.1. Positions of the standard sections monitored in the Barents Sea. A is fixed station Ingøy, B is Fugløya-BearIsland, C is North cape-Bear Island, D is Vardø-North, E is Kola, F is Sem Island-North G is Kanin section and H is Bear Island-East section.

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 per 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 per 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

* Taken once per year back to 1953

** Taken once per year back to 1964

*** The Sem Island section is not observed each year

3.1.1.1 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.

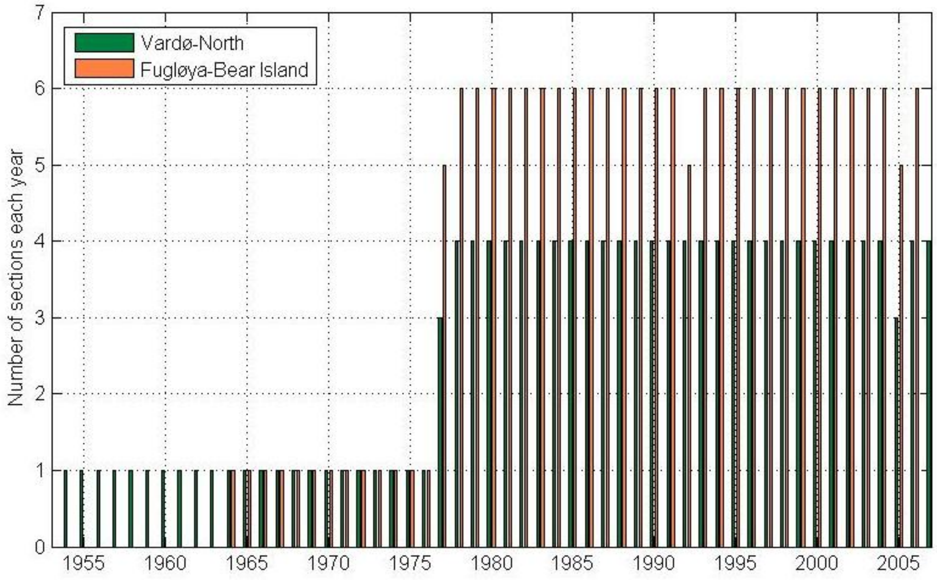

Figure 3.2. Number of observations in the Fugløya-Bear Island section and the Vardø-North section in the period 1954-2007.

3.1.1.2 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.

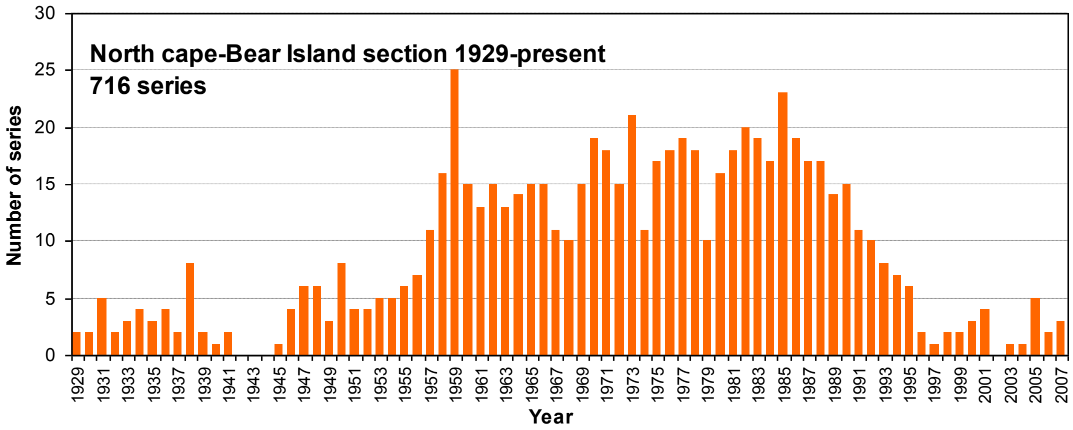

Figure 3.3. Number of observations in the North Cape-Bear Island section in the period 1929-2007.

3.1.1.3 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.

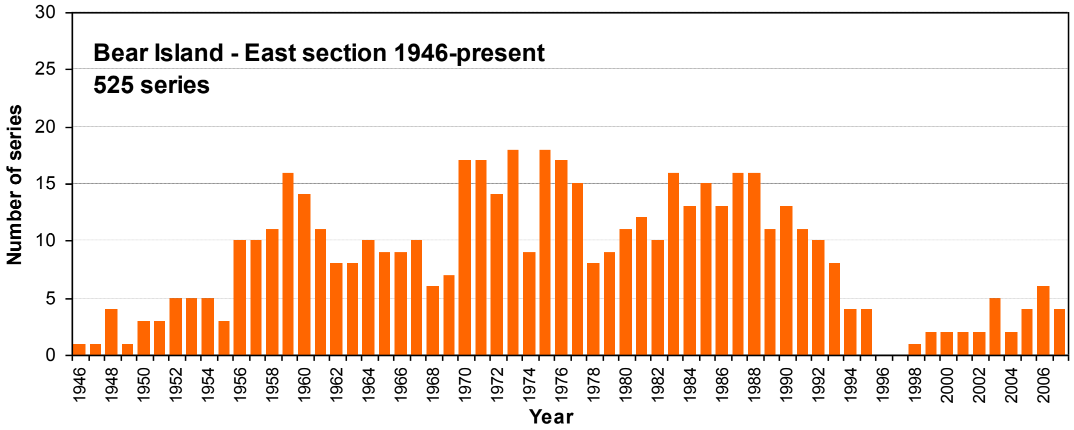

Figure 3.4. Number of observations in the Bear Island-East section in the period 1946-2007.

3.1.1.4 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.

3.1.1.5 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 exist, but in general the section has been taken quite regularly. Time-series of quarterly temperature is available from 1900-present and monthly from 1921-present.

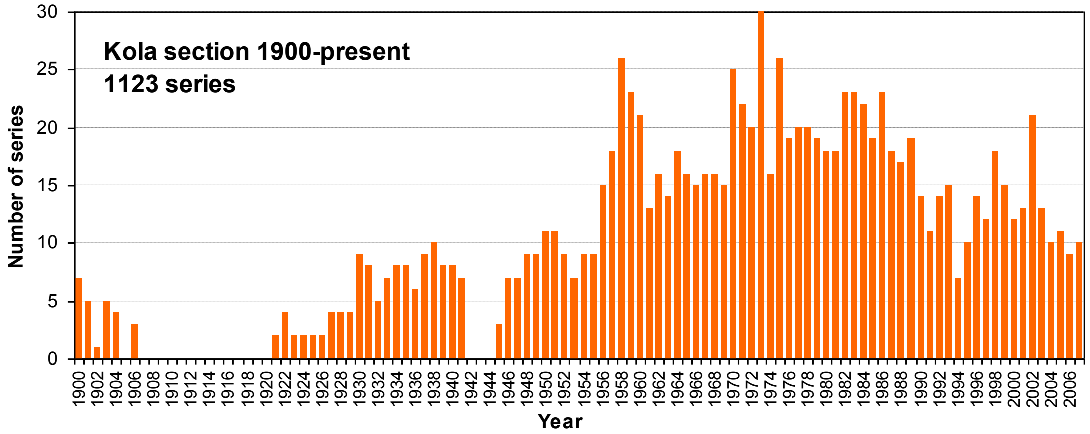

Figure 3.5. Number of observations in the Kola section in the period 1900-2007

3.1.1.6 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.

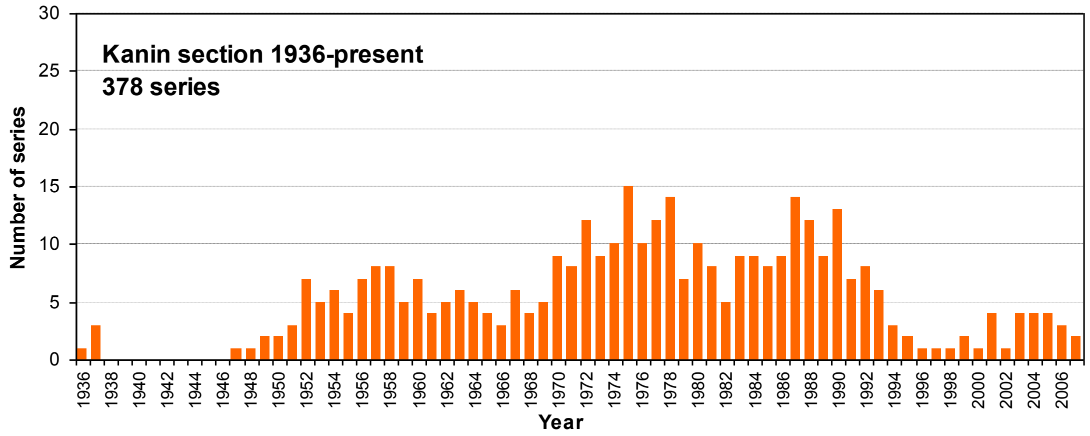

Figure 3.6. Number of observations in the Kanin section in the period 1936-2007.

3.1.1.7 Sem Island section

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.

3.1.1.8 Ingøy fixed station

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

3.2 Surveys

Area surveys are conducted throughout the year. The number of vessels in each survey differs, not only between surveys but may also change from year to year for the same survey. However, most surveys are conducted with only one vessel. It is not possible to measure all ecosystem components during each survey. 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.

3.2.1.1 Norwegian/Russian winter survey

The survey is carried out during February-early March, and covers the main cod distribution area in the Barents Sea. The coverage is in some years limited by the ice distribution. Three vessels are normally applied, two Norwegian and one Russian. The main observations are made with bottom trawl, pelagic trawl, echo sounder and CTD. Plankton studies have been done in some years. Cod and haddock are the main targets for this survey. Swept area indices are calculated for cod, haddock, Greenland halibut, *S. marinus* and *S. mentella*. Acoustic observations are made for cod, haddock, capelin, redfish, polar cod and herring. The survey started in 1981.

3.2.1.2 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.

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	Demersal species	Demersal species	-	-
Norwegian Greenland halibut survey	IMR	Aug	-	-	-	-	Greenland halibut, redfish	-	-

3.2.1.3 Norwegian coastal survey

In 1985-2002 a Norwegian acoustic survey specially designed for saithe was conducted annually in October-November (Nedreaas 1998). The survey covered the near coastal banks from the Varangerfjord close to the Russian border and southwards to 62° N. The whole area has been covered since 1992, and the major parts since 1988. The aim of conducting an acoustic survey targeting Northeast Arctic saithe was to support the stock assessment with fishery-independent data on the abundance of young saithe. The survey mainly covered the grounds where the trawl fishery takes place, normally dominated by 3 - 5(6) year old fish. 2-year-old saithe, mainly inhabiting the fjords and more coastal areas, were also represented in the survey, although highly variable from year to year. In 1995-2002 a Norwegian acoustic survey mainly for coastal cod was conducted along the coast and in the fjords from Varanger to Stad in September, just prior to the saithe survey described above. This survey covered coastal areas not included in the regular saithe survey. Autumn 2003 the saithe- and coastal cod surveys were combined and the survey design was improved. The survey now also covers 0-group herring in fjords north of Lofoten.

3.2.1.4 Joint ecosystem autumn survey

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

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

3.2.1.5 Russian autumn-winter trawl-acoustic survey

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

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

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

3.2.1.7 Norwegian Greenland halibut survey

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

3.3 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.

3.4 Fish stomach database

In the mid-1980s, a joint project was initiated by IMR and PINRO to study diet and food consumption of the Barents Sea fish in mid-1980s (Mehl and Yaragina, 1992). The main target species was cod, but other pelagic (capelin, polar cod, herring and blue whiting) and demersal (haddock, Greenland halibut, long rough dab, saithe etc) fishes were studied in recent period.

Cod stomachs have been sampled on Russian and Norwegian surveys as part of the regular sampling procedures (Mehl and Yaragina 1992). Cod stomachs have also been sampled on Russian commercial vessels with PINRO observers onboard. The sampling procedures have changed over time, including the number of stations sampled, spatial coverage of the sampled stations and the number of stomachs per station. Currently, 1 stomach per 5 cm length group of cod is taken per station for both Norwegian and some Russian research surveys (which are a part of joint Russian-Norwegian surveys). The sampling procedures on Russian commercial vessels and national research surveys are different, where usually 25 stomachs are analysed from each trawl station using random sampling. From 1984-1995 between 5-10 thousands stomachs were analyzed per year (Figure 3.7). Since 1996 when new methods of stomach content analysis were applied in PINRO, stomach numbers increased up to 15-20 thousand and then to 35 thousand stomachs of all species per year. Total stomach numbers analyzed by PINRO and IMR was approximately 380 thousand by the end of 2006 (Dolgov et al., 2007).

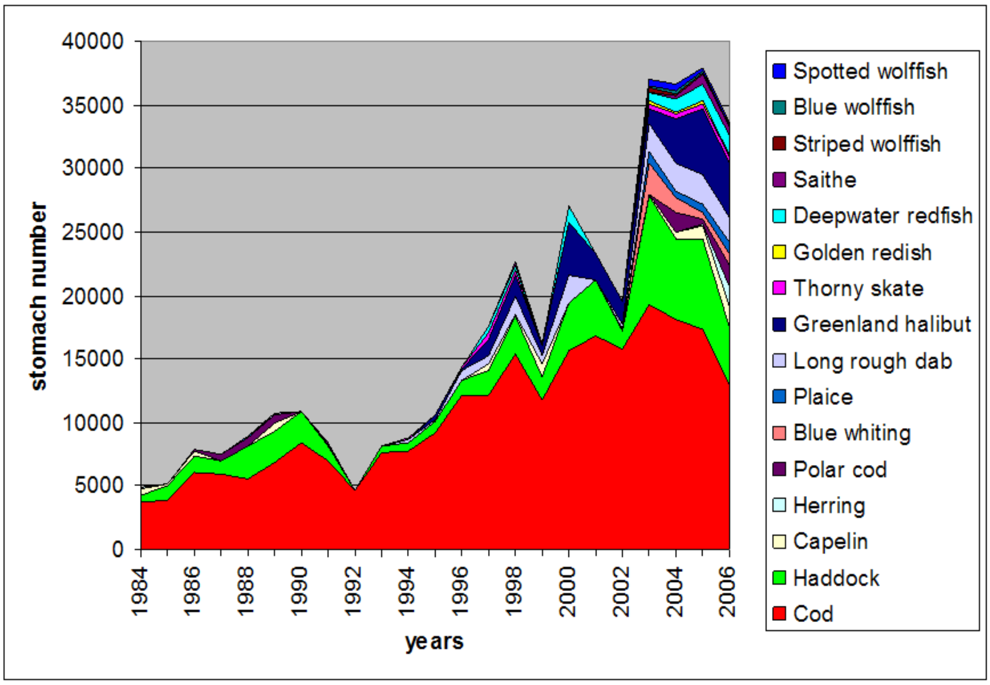

Figure 3.7. The number of main fish stomachs analyzed by IMR and PINRO by species and year. The Joint data consists mainly of cod after 1991.

PINRO has long term data on capelin stomach content, whereas IMR has very little data available. With the initiation of a project in 2005 at IMR it was agreed to make a joint PINRO/IMR pelagic fish data base similar to the one existing for cod. Capelin stomachs were sampled both by Norwegian and Russian vessels during the ecosystem cruises in 2005-2007 in autumn (August-September). In IMR cruises, up to 10 capelin stomachs per station were collected whereas PINRO collected up to 25 fish stomachs per station. The IMR collected capelin stomachs were frozen while the ones collected by PINRO were preserved in formalin. Both the Norwegian and Russian samples were later analysed at the laboratory and these data were put into the common pelagic database. Table 3.3 provides a summary of the 2005 and 2006 data. Division by a factor of 5 was used when converting wet weight of stomach contents to dry weight. The joint PINRO/IMR work on pelagic fish data base will continue in the coming years and in addition to capelin, feeding of polar cod will be also investigated from 2007 onwards. We will examine the competition for food between capelin and polar cod, especially in areas where feeding of these two species overlap.

Table 3.3. Summary of the number of capelin stomachs collected, average length, average weight (wet) of capelin and Total Fullness Index (TFI- dry weight) in 2005 and 2006.

Year	**Institute**	**No. of fish**	**Length(cm)**	**Weight (g)**	**Mean TFI**
2005	IMR	70	13,45	12,60	0,158
	PINRO	180	13,87	15,10	0,271
2006	IMR	238	14,46	16,00	0,168
	PINRO	293	13,73	14,80	0,223

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.

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

3.6 Monitoring divided by ecosystem components

3.6.1.1 Climate monitoring

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

3.6.1.2 Phytoplankton monitoring

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

3.6.1.3 Zooplankton monitoring

Zooplankton area coverage is monitored during the joint autumn ecosystem survey. Joint investigations have taken place since 2002. Regular sampling by IMR began in 1979. A Juday net is used to obtain zooplankton samples by PINRO, where as IMR use WP2 as a standard zooplankton gear. In 2005 comparisons were made between the Juday (37 cm in diameter, 180μm) and WP2 (56 cm in diameter, 180μm) net catches from the joint autumn cruises both with regard to biomass and species composition. The biomass values obtained by the two gears yielded quite similar results. A report on these comparisons of the two gears was prepared at a joint meeting held at IMR in May 2006 and the EcoNorth symposium in Tromsø in March 2007. During the Ecosystem surevey in august-september 2007 a specially designed double-net system, holding side by-side one Norwegian WP2 net and one Russian Juday net, was used to sample the water column at selected stations in order to compare the sampling efficiency of the two nets for various mesozooplankton components. A total of 19 hauls were conducted with the double-net system. Samples have been worked up for biomass comparisons, and a special workshop was arranged in Bergen 22-26 October 2007 where most of the samples were analyzed for species composition and abundance alternatively by Russian and Norwegian specialists. The results of this work will hopefully be reported later in 2008. All double-net hauls were operated with a vertical speed of 0.5 m s^{-1} from RV G.O. Sars.

Monitoring of zooplankton along the Fugløya-Bear Island section by IMR started in 1987 and are now conducted 5-6 times each year usually in January, March/April, May/June, July/August and September/October. In addition the Vardø-N section is sampled ~4 times a year. However, data prior to 1994 are scarce and does not give a full seasonal coverage. The WP2 plankton net has been used regularly during this monitoring since 1987. In addition vertically stratified MOCNESS tows are taken during the two-month Ecosystem survey in August-September each year, approximately one haul pr. day.

Regular macroplankton 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.

3.6.1.4 Benthos monitoring

Monitoring of the shrimps and the benthos community takes place during the joint autumn ecosystem survey. To cover a need of basic mapping of the bottom animals in the Barents Sea the project MAREANO started its activity in summer 2006. Within the next years the southern ice-free areas of the Barents Sea will be mapped. The joint autumn ecosystem survey will also supply a historical benthic mapping started by PINRO in the early 1930's, continued in the 1960's and followed up from year 2000. Joint red king crab monitoring surveys has been maintained in the southern coastal Barents Sea every year. The king crab stocks and life stages are targeted at these surveys. In addition to catch data the surveys are the main data source for the assessment of the stocks.

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

In order to make a method capable to follow biomass fluctuations in the Barents Sea long term monitoring areas was establishment (Figure 4.26). The areas were selected from criteria's such as: time and cost realisms, human impacts and natural variation, geographical variation. The six areas have been discussed and represent following background (Table 3.4).

Table 3.4. Area chosen in the Barents Sea and adjacent water for monitoring of the changes under influences different factors.

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

3.6.1.5 Shellfish monitoring

Since 1982 annual trawl surveys were conducted to gather information on shrimp stock biomass and demographic composition for use in the assessment. From 2004 onward, the survey has been a joint Russian-Norwegian operation: 'the Russian-Norwegian ecosystem survey of the Barents Sea (Figure 2.14).

3.6.1.6 Fish monitoring

Most of the area surveys mentioned above have monitoring of commercial fish species as their main objective. The different fish stocks and life stages are targeted at these surveys. In addition to catch data the surveys are the main data source for the assessment of the stocks. Data on non-target fish species (abundance, weight, length distribution etc.) have also been collected on these surveys during the last ten years.

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

3.6.1.7 Mammals monitoring

Regular monitoring of some marine mammals in the Barents Sea is carried out by sighting vessel surveys of cetaceans provide abundance estimates every 6 years. Since 2002 distribution of marine mammals in the Barents Sea are observed from research vessels during the ecosystem survey. In addition aircraft observations and observations from fishing vessels with observers are used. In the White Sea aircraft observations are used to estimate the abundance of harp seals.

3.6.1.8 Birds monitoring

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

4 Current state and expected situation of the ecosystem

4.1 Overview of current state

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

4.1.1.1 Climate

The temperature in the Barents Sea has been above normal in recent years, and is currently close to an all-time high for the period where observations are available. The sea temperature in the entire Barents Sea was among the warmest ever observed in 2007. 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. Inflow of Atlantic waters at the western entrance was low in 2007. In 2007 the extent of sea ice was generally much less than the long-term mean, with no ice in the summer and the ice coverage in 2008 is expected to continue to be low.

4.1.1.2 Phytoplankton and zZooplankton

The spring bloom of phytoplankton in 2007 was relatively early. In addition to available nutrients the onset of the spring bloom depends heavily on factors such as stratification and light. In 2007 the average zooplankton biomass was slightly below the long-term mean, and the spatial coverage revealed very low zooplankton biomass between longitudes 30-40ºE (<78°45′N) and somewhat lower and more irregularly distributed biomass in the western part of the Barents Sea compared to previous years.

4.1.1.3 Benthos

Several species of bottom dwellers are found anchored or crawling on the sea bottom, or living in between already existing communities of benthic animals creating a multi-species habitat. By-catch in bottom trawling indicates that the current distribution of megabenthos in the Barents Sea is highly variable from area to area, with “hot spots” at the Tromsø Flake (mainly sponges), on the Spitsberg Bank, the Olga Strait, Goose Bank and Novaya Zemlya Bank..

The indices of stock size of Northern shrimp (*Pandalus borealis*) have increased from 2004 to 2006. A decrease of 18% was observed from 2006 to 2007. In 2007, the distribution of red king crab **(***Paralithodes camtschaticus***)** was characterized by dense concentrations in the eastern part of the Russian waters where the majority of the catches were taken. The commercial stock index in 2007 decreased by 1.1 times compared with 2006.Management of the red king crab in the Barents Sea was a joint management between Russia and Norway until 2006 when the two parties decided to carry out separate management in the two different economical zones. New legislations for the management of the king crab in Norwegian waters will be implemented in 2008. In 2007 the first directed trawl survey of the Barents Sea snow crab stock was conducted. The highest density of snow crab (60-100 individuals per km2) was registered on the northern slope of the Goose Bank and in the Goose Land shallow waters. Most part of the Iceland scallop (Chlamys islandica) fishable stock was found in the area of Svyatoy Nos Cape (Svyatoy Nos scallop settlement) where the basic fishery was concentrated. Since 2005 a tendency for a growth in the fishable stock has been observed. The survey in 2007 showed no major changes in stock status at the monitored bed in Troms compared to an investigation in 2005. There is relatively high abundance of commercial sized scallops in the area and the recruitment is good.

4.1.1.4 Fish

The cod stock was estimated to remain at a relatively stable level in 2007 with a SSB above the precautionary approach level B_{pa} (i.e. having full reproductive capacity), being exploited within the range that will lead to high long-term yields (indicated to be in the F range 0.25-0.50).The stock of haddock was estimated to be increasing and well above B_{pa} in 2007. However, the fishing mortality was somewhat above F_{pa}. There was a small increase in the survey indices of redfish in 2007 but they are all still at a historically very low level. The estimated stock size of Greenland halibut also remained stable in 2007. Based on the most recent estimates of SSB and recruitment of capelin ICES classifies the stock as having reduced reproductive capacity. Observations during the international 0-group survey in August-September 2007 indicated that the size of the 2007 year class is above the long term mean. The estimated stock size of herring and blue whiting in the Barents Sea decreased further in 2007. The abundance of herring in the Barents Sea is believed to be at a relatively low level in 2008. The polar cod stock is presently at a high level.

4.1.1.5 Marine mammals

Both high temperatures and increasing of capelin abundance are likely to have influenced the marine mammal distributions in 2007 in the Barents Sea. The most abundant and widely distributed cetaceans were white-beaked dolphins, minke whales and humpback whales, while harbour porpoises were abundant along the coast. Although the most abundant marine mammals were observed associated with capelin, their distributions also overlapped with herring and polar cod, and likely with krill. There are evidences on decrease in harp seal pups production in the White Sea, and in the total abundance of this population during the last years.

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

4.2 Climate

By A. P. Pedchenko (PINRO), R. Ingvaldsen (IMR), A. L. Karsakov (PINRO), V. K. Ozhigin (PINRO) and O. Titov (PINRO)

4.2.1 Atmospheric conditions

4.2.1.1 Wind field

In winter 2006/2007, a low-pressure trough related to the Icelandic Low dominated the northern North Atlantic, the Nordic Seas and stretched deep into the Barents Sea (Figure 4.1). Small negative air pressure anomalies (~ -1 mb) were centered over the Svalbard archipelago, while small positive anomalies (~ 1 mb) were established over the southern Barents Sea. Such an air pressure pattern would have strengthened the southwesterly winds and increased transport of warm air and water in the southern Barents Sea. Relatively strong southerly winds prevailed over the eastern part of the sea, while light easterlies dominated the northern and western Barents Sea. In summer 2007, a low-pressure trough stretched over terrestrial area from the western Siberia to Scandinavia. Horizontal air pressure contrasts were considerably smaller than in winter, and weak easterly and northeasterly winds prevailed over most of the Barents Sea (Figure 4.1). Stronger northerly winds dominated the Barents Sea Opening and Bear Island – Svalbard area.

4.2.1.2 Air temperatures over the sea

Air temperature data were taken at http://nomad2.ncep.noaa.gov and averaged over western (70-76°N, 15-35°E) and eastern (69-77ºN, 35-55ºE) parts of the sea. In the first half of 2007, the air temperature over the Barents Sea was well above normal, with maximum positive anomalies (6.0-7.0 ºC) in the eastern sea in February-April. In summer and early autumn temperature anomalies decreased to their long-term means. In November-December, over most of the sea, air temperature was, on average, 2.0-3.0 ºC higher than the long-term mean (Figure 4.2).

4.2.1.3 Air temperature at weather stations

Table 4.1 summarizes air temperature anomalies at some meteorological stations at the western and southern Barents Sea during the period from late 2006 through 2007. In winter 2006/2007, air temperature over the region was considerably warmer-than-normal (by 0.0-4.0 °C), with highest anomalies at the Svalbard airport (6.0-7.0 °C) and Murmansk (12.0 °C in December). However February 2007 was colder-than-usual at all stations but Svalbard airport and Bear Island. During April-September temperature anomalies were predominantly positive but considerably smaller than in winter. During late autumn and early winter (October-December) positive anomalies rose again compared to summer months and ranged from 1.0 °C to 7.1 °C. Mean annual air temperature in 2007 was warmer-than-average by 0.9-3.2 °C. Mean annual air temperatures in 2007over the northwestern Barents Sea (Svalbard airport and Bear Island) were colder than in 2006, while at the southern stations (Tromsø, Vardø, Murmansk and Kanin Nos) they were warmer than the previous year.

Table 4.1. Mean air temperature anomalies at weather stations around the Barents Sea in December 2006 – December 2007, yearly mean anomaly in 2007, maximum anomalies and years when they were observed.

Station	Year/Month													2007 mean	Max/Year
	2006	2007													
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Svalbard airport	6.0	5.7	5.8	7.0	1.3	2.0	2.4	1.5	1.1	1.3	2.7	3.7	3.7	3.2	4.3 2006
Bear Island	5.7	3.3	2.2	4.0	1.3	1.3	1.4	0.0	0.9	0.9	3.0	2.7	5.3	2.2	2.9 2006
Tromsø	3.4	0.2	-3.6	2.6	0.4	0.8	0.2	1.8	0.2	-0.3	3.3	1.0	4.0	0.9	1.5 1938
Vardø	3.3	2.5	-1.2	3.5	1.6	0.9	1.3	-0.3	1.3	1.0	3.2	1.3	4.1	1.5	1.5 1937/2005
Murmansk	12.0	2.0	-6.9	4.9	1.8	0.5	-0.7	-1.2	2.4	0.8	4.3	2.1	7.1	1.4	2.0 2005
Kanin Nos	2.5	4.7	-1.1	4.4	2.5	0.4	0.6	1.1	2.4	2.0	4.5	1.2	4.4	2.3	2.5 1937

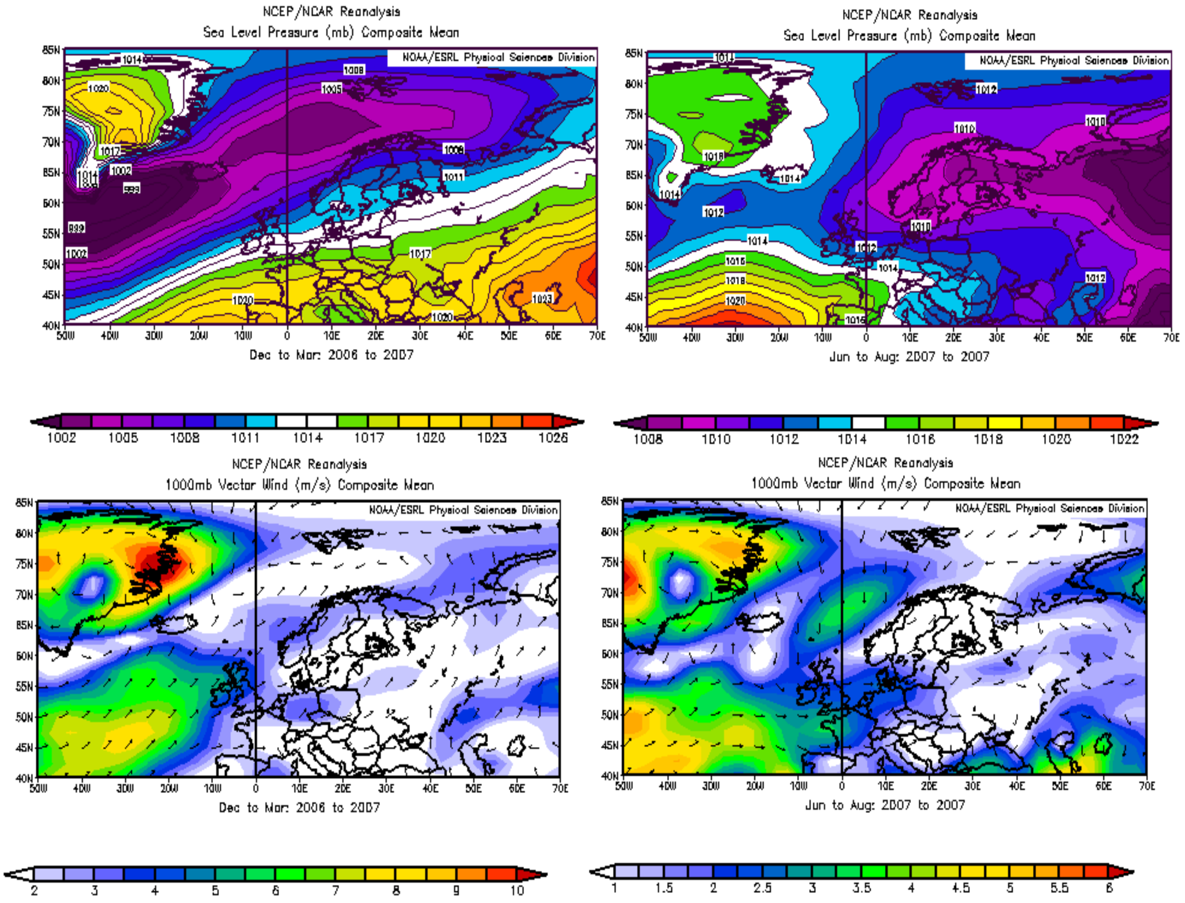

Figure 4.1. Sea level pressure (upper) and wind vectors (lower) in December-March 2006-2007 (left plates) and. June-August 2007(right plates).

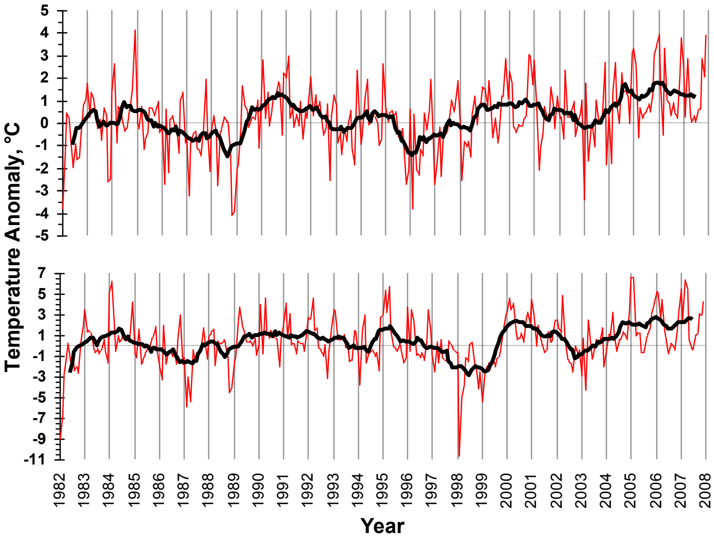

Figure 4.2. Air temperature anomalies over the western (above) and eastern (below) Barents Sea in 1982-2007.

4.2.2 Hydrographic conditions

4.2.2.1 Sea surface temperature

Sea surface temperature (SST) data were taken at http://iridl.ldeo.columbia.edu and averaged over the Bear Island – Svalbard area (74-79ºN, 08-25ºE), central (71-74ºN, 20-40ºE) and southeastern Barents Sea (69-73ºN, 42-55ºE). In winter and spring, over most of the Barents Sea, SST was higher-than-normal, with maximum anomalies of 0.2-1.1 ºC in the central and eastern areas. In May-June, a weaker than usual atmospheric warming of the sea surface caused a decrease in SST anomalies. As a result, there was a transition from positive to negative SST anomalies in the eastern Barents Sea in June. In the second half of the year, SST anomalies increased again to well above normal values all over the sea with maximum in October (0.5-1.7 ºC) (Figure 4.3).

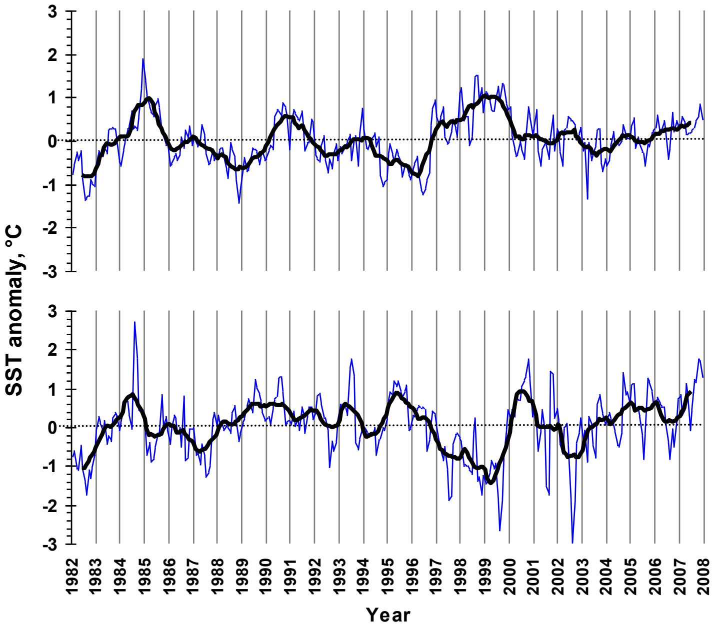

Figure 4.3. Sea surface temperature anomalies in the western (above) and eastern (below) Barents Sea in 1982-2007.

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

The time series from the coastal waters at the fixed station Ingøy show that from January 2006 to March 2008 the temperatures were above the long-term mean (Figure 4.4). The deviation from the mean was less during summer at the surface. The highest deviations were in 250 m depth January-March 2006 when the anomalies were more than 2°C.

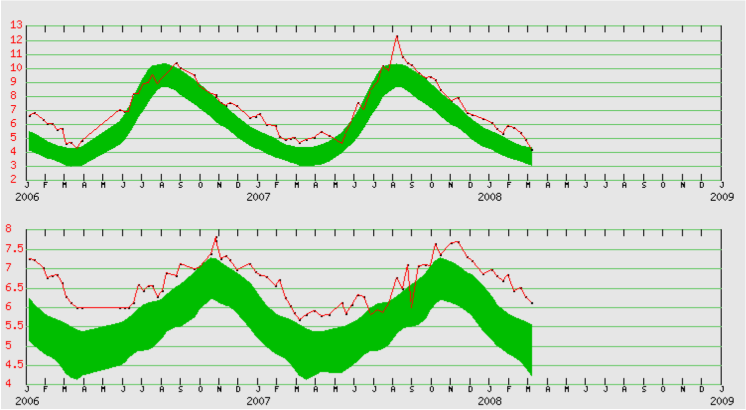

Figure 4.4. Monthly mean temperature at 1 m and 250 m depth at the fixed station Ingøy, northern Norway, situated in the Coastal Current at the entrance to the Barents Sea. Vertical axis is temperatures (°C) and horizontal axis is month. The green areas are the long-term mean for the period 1936-1944 and 1968-1993 +/- one standard deviation and represent the typical variations.

At the Fugløya-Bear Island section, a positive temperature anomaly of 1.55°C was observed in January 2007, and this is an all time high since the time series started in 1977 (Figure 4.5). The temperature stayed high throughout 2007, but as has been usual for the last years the anomalies decreased through the year and in October the temperature were 0.6 above the long-term mean. The annual mean temperature for 2007 was a little lower than for 2006, the warmest year ever observed in the Barents Sea. In January 2008 the temperature anomaly at the Fugløya-Bear Island section was 0.78°C, while in March the anomaly at Vardø-N was 1.58°C above the long-term mean, which again is a new all time high. The salinity variations are similar to those in temperature, and there has been a high salinity in the last 6 years.

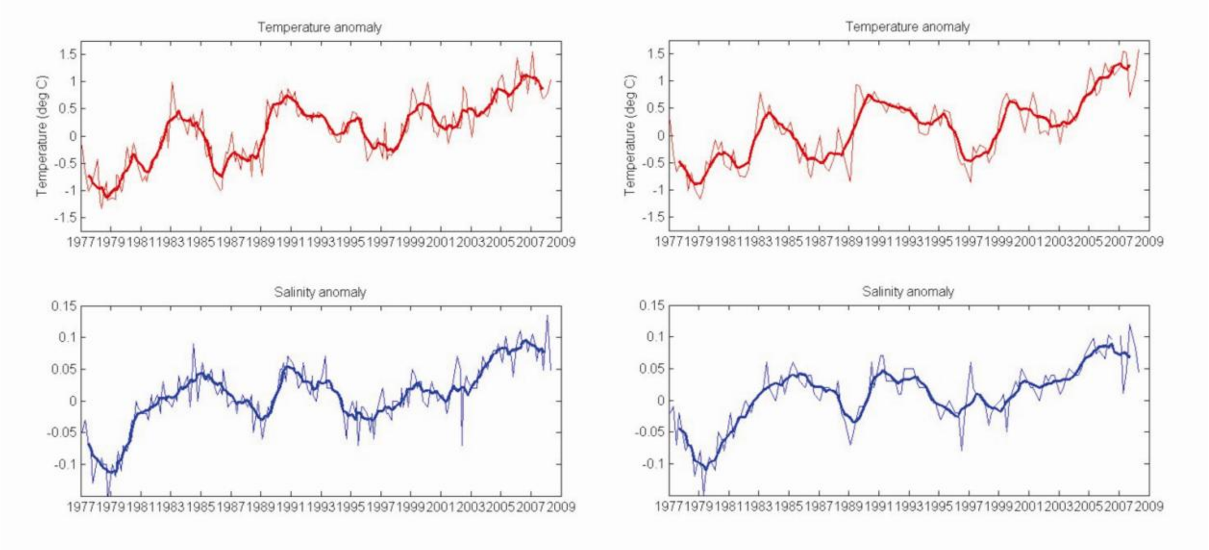

Figure 4.5. Temperature (upper) and salinity (lower) anomalies in the 50-200 m layer of the Fugløya-Bear Island section (left plates) and Vardø-N section (right plates).

According to the observations along the Kola section, which was made 9 times in 2007, sea temperature in the active layer (0-200 m) of the southern Barents Sea, was significantly higher than the long-term means throughout the year (Figure 4.6). From February through May, the temperature of the coastal waters (St. 1-3) as well as in the Murman Current (St. 3-7) was about 1.2-1.3 °C warmer-than-normal. In March and April it was the highest temperature since 1951. In the coastal waters, positive anomalies of temperature decreased to 0.7-08 °C in August-September and rose to 1.0-1.2 °C in October-December. In the Murman Current (St. 3-7), a decrease of temperature anomaly (to 0.9-1.0 °C) was observed from June to December.

In the southern Barents Sea in 2007, water salinity was typical for warm years. Both in the coastal waters and in the Murman Current salinity was higher than the long-term means. Some decrease in positive salinity anomalies was observed in September-December (Figure 4.6).

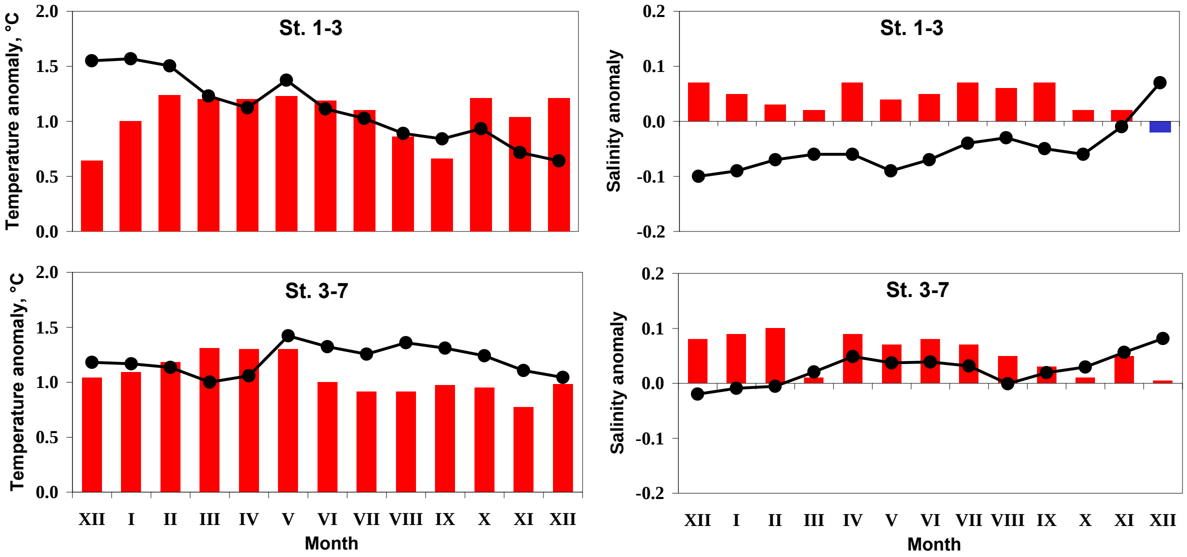

Figure 4.6. Monthly mean temperature (left) and salinity (right) anomalies in the 0-200 m layer of the Kola section in 2006 and 2007. St.1-3 – coastal waters. St.3-7 – Murman Current (Anon, 2008).

On the whole, in 2007, in the upper 200 m layer of the Kola section, the mean annual water temperature was close to that of 2006, which was highest on record for more than 100 year history of observations along the section (Figure 4.7). Mean annual salinity in the 0-200 m layer of the section was higher than usual, and higher than in 2006.

Hydrochemical observations show that 2007 in the Barents Sea is a continuation of the period characterized by a gradual increase in oxygen saturation of bottom layers in the southern Barents Sea, which has started in 2002 (Figure 4.8).

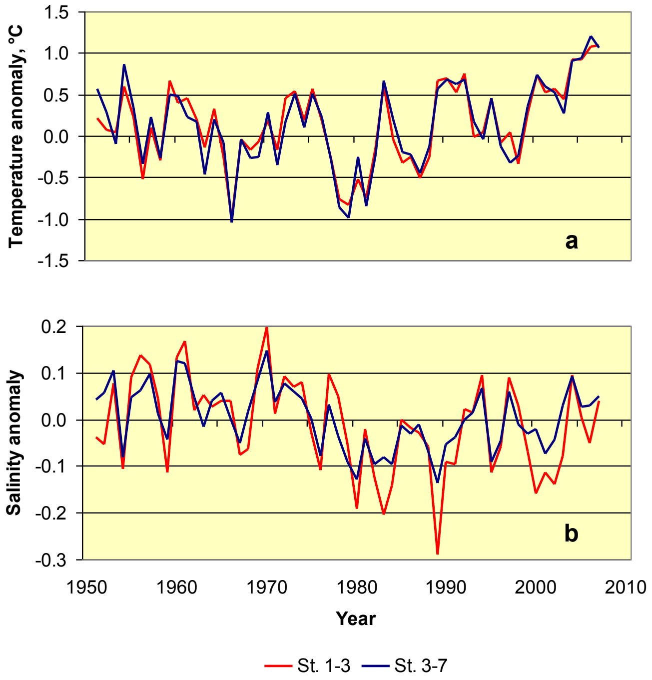

Figure 4.7. Mean annual temperature (a) and salinity (b) anomalies in the 0-200 m of the Kola section in 1951-2006. St. 1-3 – coastal waters, St. 3-7 – Murman Current (Anon, 2008).

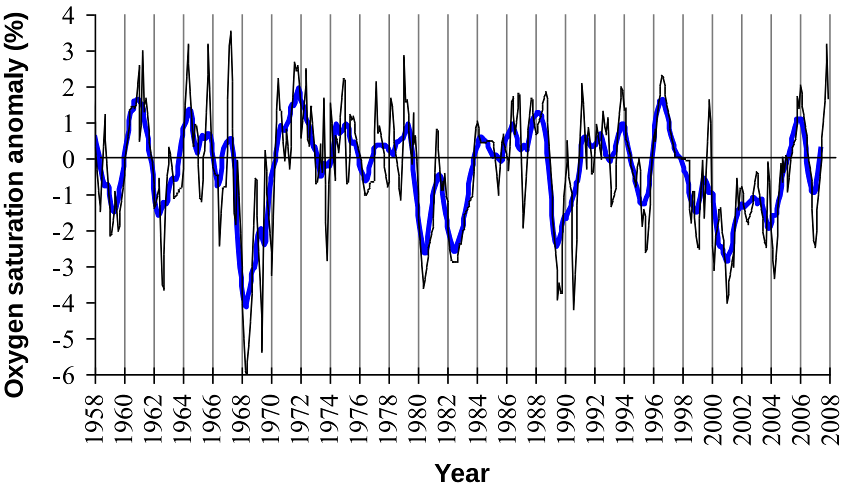

Figure 4.8. Monthly and annual oxygen anomalies in the bottom layer of the Kola section (Anon., 2008).

In the North Cape - Bear Island Section, the observations were made in February, June and September. Positive anomalies of temperature in the 0-200 m layer of the North Cape Current decreased from 1.4 ºC in February to 1.1 ºC in June and further to 1.0 ºC in September.

In 2007, the section Bear Island – West (along 74º30’N) was occupied 3 times. Temperature in the eastern branch of the Norwegian Atlantic Current (74º30’N, 13º30’-15º55’E), in the 0-200 m layer, was significantly warmer-than-normal. The positive anomalies increased from 0.7 ºC in February to 1.2 ºC in November.

During 2007, the section Bear Island – East (along 74º30’N) was made 5 times. Temperature in the 0-200 m layer of the northern branch of the North Cape Current (74º30’N, 26º50’-31º20’E) was significantly higher than the long-term average, with the maximum positive anomalies (1.4-1.5 ºC) registered in February, March and June. In August and October, the temperature of Atlantic waters remained high, however positive anomalies of temperature decreased to 1.1 – 1.2 ºC.

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

In August-September 2007, there were warmer than normal temperatures in 100 m depth in most of the Barents Sea (Figure 4.9). The highest anomalies were observed in the central parts, with anomalies of 1- 2^{o}C. In the southwestern parts the temperatures in the inflowing Atlantic Waters were 0.5^{o}C above the normal while the Coastal Waters was close to normal.

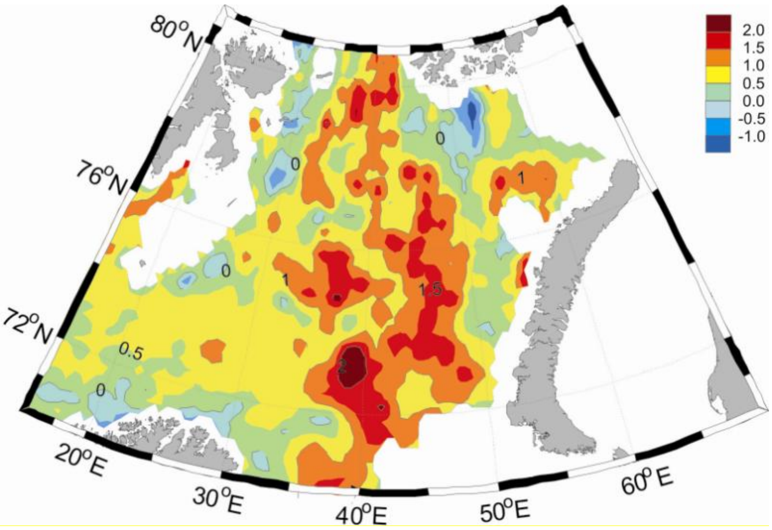

Figure 4.9. Temperature anomalies at 100 m depth in the Barents Sea in August-September 2007 (Anon., 2007).

In August-September 2007, in the bottom layer of the Barents Sea, water temperature, on the whole, corresponded to that one in anomalous warm years. Waters with positive anomaly of bottom temperature occupied more than 90% of the surveyed area**Feil! Fant ikke referansekilden.**), and at about 35% of it, the anomalies were maximal since 1951. The highest anomalies of temperature in bottom layer (>2 ºC) were observed in the North Cape and Murman Currents.

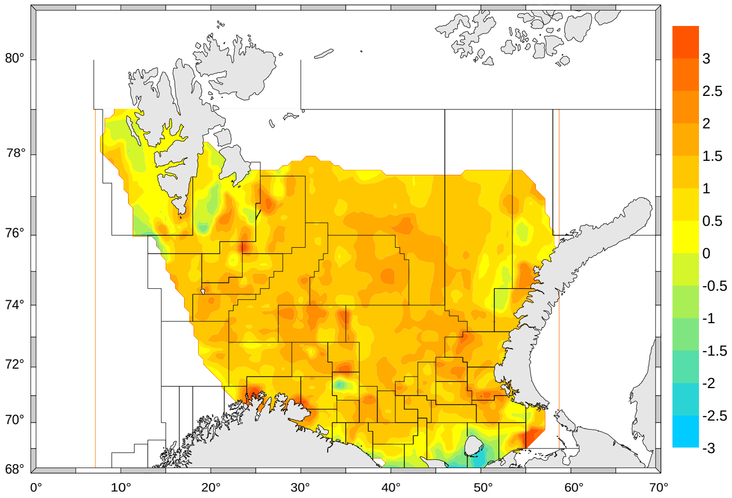

Figure 4.10. Bottom temperature anomalies in the Barents Sea in August-September 2007 (Anon, 2008).

4.2.3 Currents and transports

The temperature and the volume flux of the inflowing Atlantic Water in the Fugløya-Bear Island section do not always vary in phase. The temperature is mainly determined by variations upstream in the Norwegian Sea, while the volume flux to a large degree varies with the wind conditions in the western Barents Sea. The year of 2006 was a special year as the volume flux both had a maximum (in winter 2006) and minimum (in fall 2006). During winter 2007 the volume flux increased to just below the average, but then it showed a rapid decrease during spring 2007 (Figure 4.11). The observational time series has only data until June 2007, but the atmospheric wind field indicate a low inflow during summer 2007 and thereafter an increase toward the normal conditions during fall 2007.

There is no significant trend in the observed volume flux from 1997 to summer 2007.

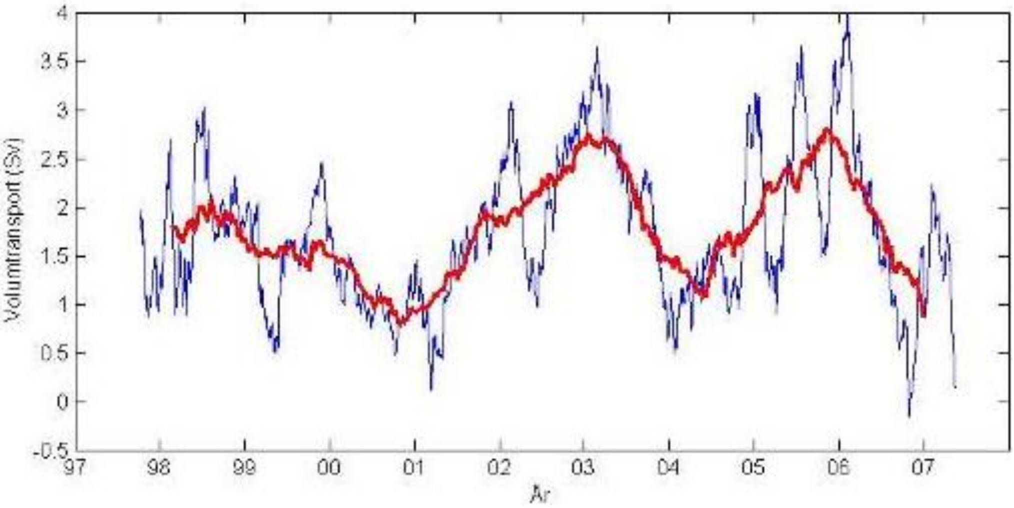

Figure 4.11. Observed Atlantic Water volume flux through the Fugløya-Bear Island section estimated from current meter moorings. Three months (blue line) and 12-months (red line) running means are shown.

Monthly wind-driven and total volume fluxes and their anomalies were calculated with a numerical model (Trofimov, 2000) for the main currents of the Barents Sea in 2007 (Figure 4.12).

In comparison with the long-term mean, in 2007, on the whole, the general circulation was weaker in the western part of the Barents Sea, stronger in the eastern part and near normal in the central one. Whereas in comparison with the previous year, the general circulation was weaker all over the sea. In 2007 the total flux through the section crossing the Novaya Zemlya Current was above normal throughout the year but it was less than in 2006.

In 2007, on the whole, the wind-driven circulation in the Barents Sea was weaker than in 2006.

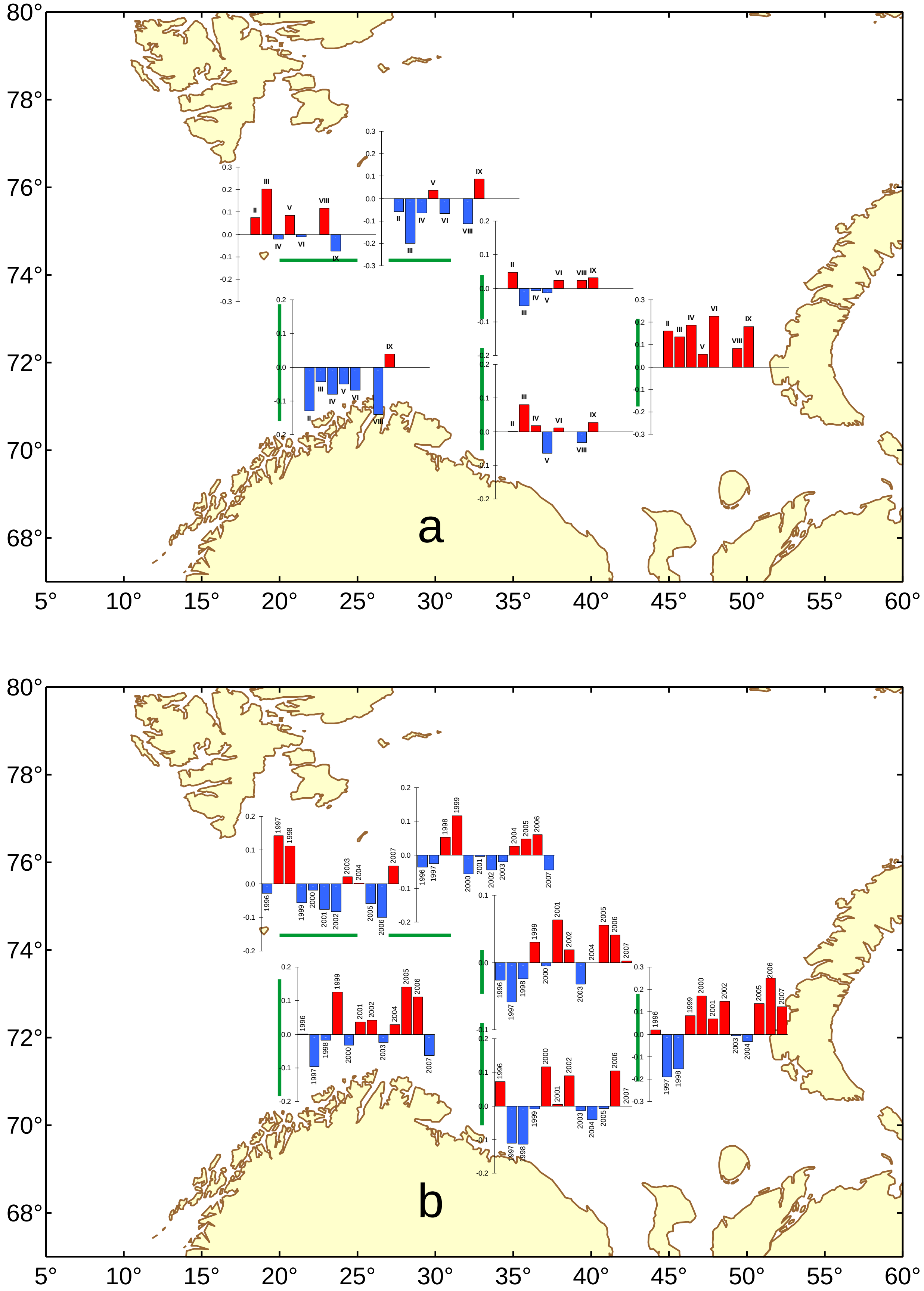

Figure 4.12. Monthly (a) and annual (b) total flux anomalies (Sv) in the Barents Sea in 2007 and for the period of 1996-2007 respectively.

4.2.4 Ice conditions

During the year, the sea ice extent was generally much less than the long-term mean (Figure 4.13). The greatest ice coverage was observed in February, 36% of the sea area, that was 21% less than normal. Minimum ice extent was in September when there was no ice in the sea. Ice edge was located to the north of 81°N. In October ice coverage amounted only 1% of the sea area, i.e. 16% lower-than-normal. In November it was the lowest for the corresponding month since 1951.

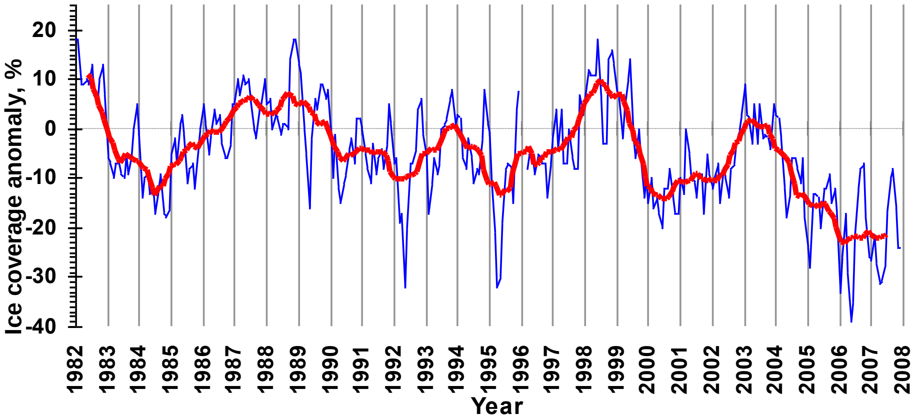

Figure 4.13 Anomalies of mean monthly ice extent in the Barents Sea in 1982-2007. A blue line shows monthly values, the red one – 11-month moving average values (Anon., 2008).

4.2.5 Expected situation

4.2.5.1 Temperature predictions

The natural first environmental parameter to try to forecast is sea temperature. Because the ocean has a ”long memory”, as compared to the atmosphere, it is feasible, at least a priori, to realistically predict ocean temperature much further ahead than the typical weather forecast.

The prediction is complicated by the variation being governed by processes of both external and local origin operating on different time scales. Thus, both slowly moving advective propagation and rapid barotropic responses due to large-scale changes in air pressure must be considered.

Advection may be considered a natural starting point for predicting Barents Sea temperatures, and temperature variations in the southern Norwegian Sea is often seen 2-3 years later in the Barents Sea. As the temperature in the Norwegian Sea has increased since 2005, and because the inflow is expected to increase from the low inflow in 2007, the temperatures in 2008 are expected to be at least as high as in 2007.

According to computation by a prediction model (Boitsov and Karsakov, 2005), based on harmonic analysis of the Kola section temperature time series, the temperature of Atlantic water in the Murman current in 2008 is expected to be higher than the long-term mean, but most likely lower than in 2007 (Table 4.2).

Table 4.2. Predicted temperature in the Kola section (0-200 m), representing the southern Barents Sea.

	Observation	**Observation**	**Prognosis**	**Prognosis**
Year	2006	2007	2008	2009
Temperature °C	5.1	4.9	4.7	4.5

It should be stressed that the predictions in this chapter are fundamentally different from the global change scenarios for 50 or even 100 years ahead (e.g. ACIA, 2005; IPCC, 2007). These long-term trend scenarios are addressed in section 4.9.1.

4.2.5.2 Expected ice conditions

Due to the extremely warm Atlantic waters in the latest years, in combination with the fact that the ice often lag the temperature variations with a few years, and the extreme ice minimum the recent years, the ice conditions in 2008 is expected to be low.

4.3 Phytoplankton

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

4.3.1 Current state

There is large interannual and geographical variation in the starting point of the spring bloom, a variation that is large degree controlled by the stability of the water column. In 2007 low concentrations of phytoplankton was observed on the Fugløya-Bjørnøya in March with trace amount of diatoms. The same was observed at the Vardø- North transect at the time. There was a small increase in the chlorophyll concentration in April along the whole transect (Figure 4.14). Diatoms were the dominating group in the phytoplankton community. At stations close to Bjørnøya there were observed some *Phaeocystis* colonies at the time. In June high concentrations of chlorophyll (Figure 4.14) was observed at stations near Bjørnøya and Fugløya, whereas the concentration were low in the central parts. During this covering the phytoplankton community were a mix between diatoms (*Chaetoceros* spp and *Thalassiosira* spp) and smaller flagellates (included *Phaeocystis*). Covering of the transects in July (Vardø-N) and Bjørnøya-Fugløya in august showed typical summer situation, with moderate chlorophyll a concentration along the transect (Figure 4.14), with some smaller area showing higher biomass. The phytoplankton was dominated by smaller flagellates at most stations. In between there were stations with higher abundance of diatoms and larger dinoflagellates. In November the concentration of phytoplankton has decreased and only trace amount is observed. In 2007 there was observed higher concentration at some stations on the Fugløya side of the transect.

Simulations of the primary production in the Barents Sea using the ROMS numerical model showed that there has been considerable interannual variation in timing of the spring bloom at the Fugløya-Bjørnøya section during the years 1982 to 2006 (Figure 4.15). Even though we suspect the model to produce the bloom somewhat too early in the year, we expect the trends to be more correct. The model results showed that the peak of the bloom may vary with about one month from year to year and in 2007 the results indicates that the bloom was the earliest for the modelled period. Also it seems to be a long term trend towards earlier spring blooming. Figure 4.16 shows the timing of the bloom throughout the Barents Sea in 2007. It shows that the bloom was earliest at the western part of the polar front and in the southeastern part of the Barent Sea. Also close to some of the bank areas the bloom started early. Some of these banks are very shallow and water masses may be trapped there. The bank may therefore act as a barrier to downward transport of plankton cells in the same way as a stratification of the water masses. This may explain the early bloom in the bank areas.

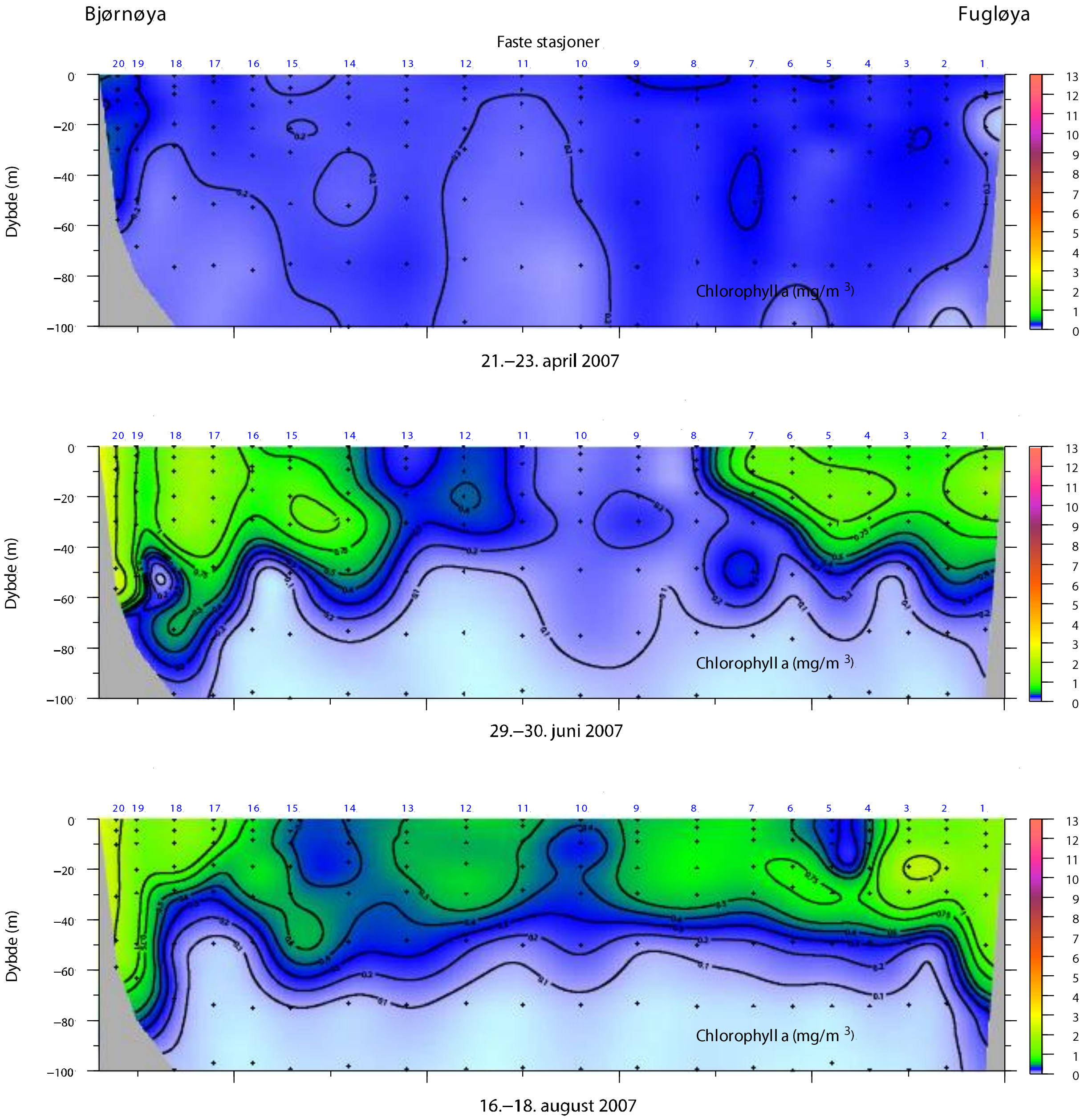

Figure 4.14. Measured chlorophyll in the upper 100 m on the transect Fugløya – Bjørnøya in April (upper panel), June (middle panel) and August (lower panel) in 2007. North is to the left.

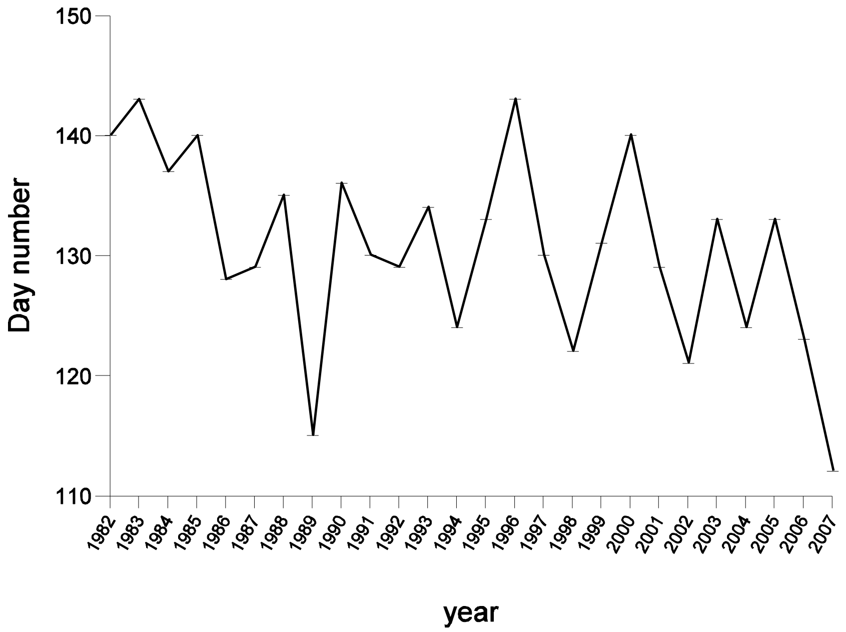

Figure 4.15. Modelled day number of peak diatom spring bloom at the Fugløya-Bjørnøya section during the period 1982 to 2007 using the ROMS numerical model.

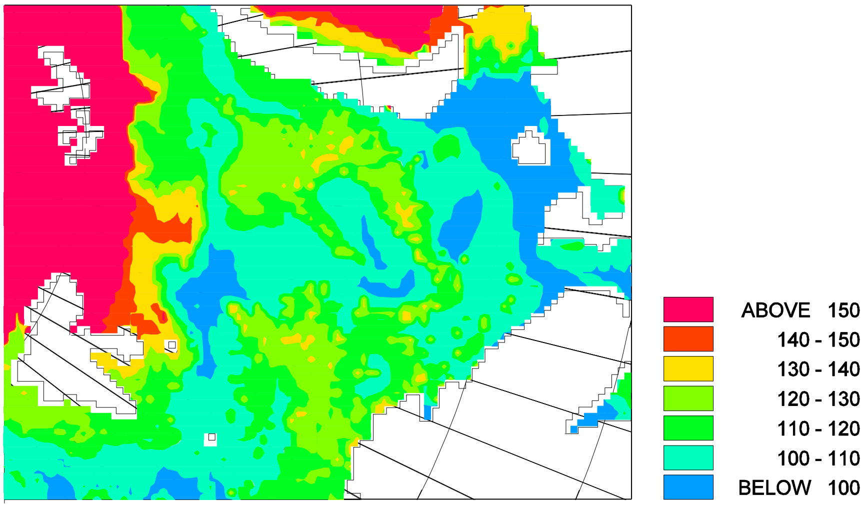

Figure 4.16. Modelled day number of peak diatom spring bloom in 2007 using the ROMS numerical model.

4.3.2 Expected situation

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

4.4 Zooplankton

By T. Knutsen (IMR), P. Dalpadado (IMR), E.L. Orlova (PINRO) and A.S. Yurko (PINRO)

4.4.1 Current state

In 2007 the average zooplankton biomass was slightly below the long-term mean, and the spatial coverage revealed very low zooplankton biomass between longitudes 30-40ºE and south of latitude 78°45′N. In the western part of the Barents Sea a somewhat lower and more irregularly distributed biomass was observed compared to previous years. North of latitude ~78°45′N and in the eastern central part of the Barents Sea (>40º E), high biomass regions comparable to those found in Atlantic waters in the west are also observed.

Figure 4.17 shows the horizontal distribution of mesozooplankton from bottom-0m, using the combined data sampled by WP2-net (used by Norway) and Juday net (used by Russia). The Russian and Norwegian data complement each other. The distribution of zooplankton biomass based on joint Norwegian and Russian biomass data is very similar to that observed during the Norwegian surveys, but Russian data add significant information particularly for the central northern and the eastern regions of the Barents Sea.

The average zooplankton biomass in the western and adjacent central Barents Sea in 2007 was 7.17 g dry weight $m^{-2.}$ The values are based on WP2 hauls (Norwegian) covering the whole water and depths less than 500m (Figure 4.17). The average biomass value in 2007 was significantly reduced compared to 2006 (8.63 g dry weight m^{-2}) for similar area coverage. The average value for 2007 is based on 145 stations relatively homogeneously distributed in the region. When combining both Juday (Russian) and WP2 data the average zooplankton biomass in 2007 amounted to 7.7 g m^{-2} dry weight. This is somewhat lower than the results observed in 2006 from both gears (8.4 g m^{-2}).

Examination of the zooplankton composition indicated predominance of the three *Calanus* species (*Calanus finmarchicus, Calanus glacialis and Calanus hyperboreus*), *euphausiids chaetognaths*, and in some cases *pteropods* that caused high biomass estimates (see details below).

When considering the Norwegian data only, the plankton distribution in 2007 is distinctly different to 2006, but the highest abundances of plankton were still observed in the western and southern part of the Barents Sea. The southern and western distribution of high zooplankton biomass observed in 2006 probably associated with influx of warmer Atlantic water penetrating north and east into Bjørnøyrenna, is much less pronounced in 2007. The region closest to the Norwegian coast in 2007 had a zooplankton biomass comparable to what was found for 2006. The distribution pattern from the Norwegian survey reflects clearly that the eastern part of the survey area east of 30ºE is poor in zooplankton biomass. However, when Russian data are considered, as they are included in Figure 4.17, it is observed very high zooplankton biomass north of Kong Karls Land (~78°45′N), from Nordaustlandet in Svalbard, to the eastern parts of the Franz Josef Land Archipelago. A high biomass region also extends from this area southwards being particularly evident east and south-east of the Central Bank. In these high biomass areas zooplankton abundance was mainly caused by *Calanus glacialis,* although *C. hyperboreus* and *M. longa* are occasionally quite important (see below for details). South of the central-eastern core of high zooplankton biomass, from Novaya Zemlja in the east, to the Varangerfjord in the west and the Kola Peninsula in the south, very low zooplankton biomass were recorded, most often typical for the shallow shelf waters of this region.

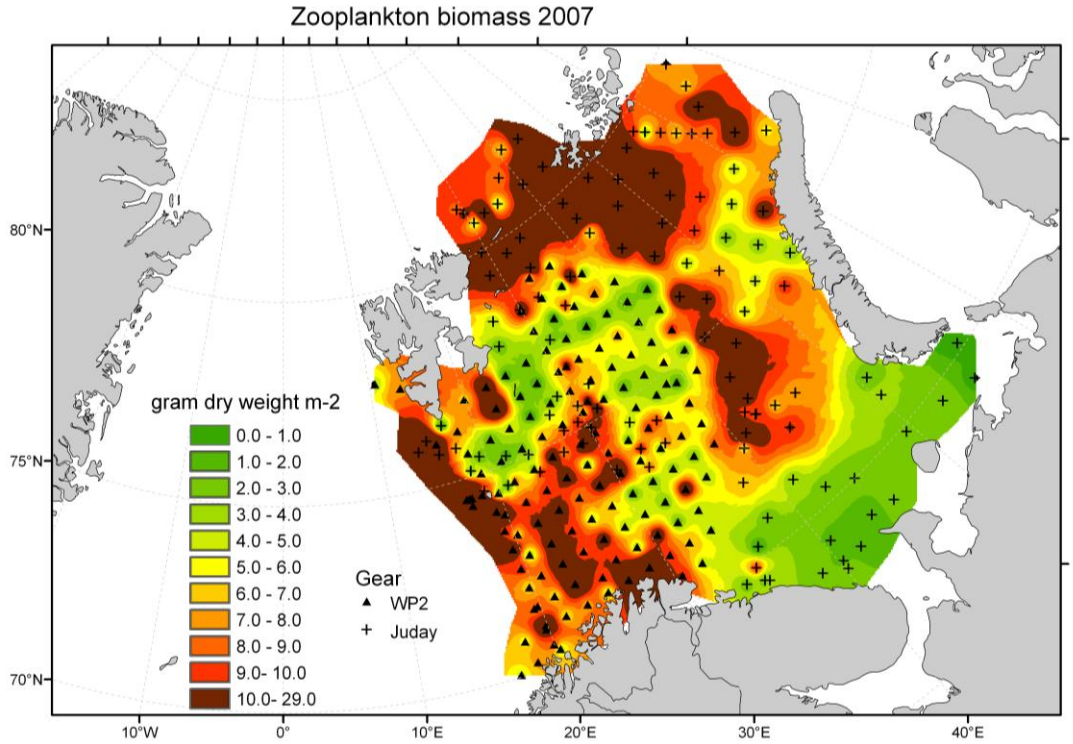

Figure 4.17. Distribution of zooplankton dry weight (g m^{-2}) from bottom-0 m in 2007. Data based on Norwegian WP2 and Russian Juday net samples.

The importance of water mass characteristics on zooplankton abundance is shown in Table 4.3. It is apparent that zooplankton abundance on average is highest in Atlantic water masses with 8.6 g dry-weight m^{-2} (compared to 11.3 g dry-weight m^{-2} in 2006) and in mixed water of Atlantic and coastal origin. The higher biomass observed in coastal water masses (6.6 g dry-weight m^{-2}) compared to what was observed in 2006 (1.6 g dry-weight m^{-2}) is supported by what can be observed from the horizontal distribution (Figure 4.17), but number of stations is low, hence the results must be interpreted with caution.

Table 4.3. Zooplankton average dry weight (g m^{-2}) in different watermass categories in 2007. Data based on WP2 net samples (Norwegian data only).

	No stations	Average dry weight (g m^{-2})	Standard deviation
North Atlantic water	77	8.6	5.6
Coast water	4	6.6	2.7
Coast/North Atlantic wate	10	8.3	5.6
Arctic water	7	5.4	5.1
Polar front water	45	5.0	4.3

It should be stressed that Russian data is not included in a Table 4.3. As the Russian surveys better cover the northern and eastern parts of the Barents Sea they could most probably add new insights to the dynamics and average zooplankton biomass of Arctic waters and Polar front water in particular.

As it has been established by the long-term observations (Bogorov, 1941; Degtereva, Nesterova, Panasenko, 1990), in the Barents Sea, biomass directly depends on seasons of the development of production processes since the periods of plankton reproduction differ in various water masses in cold and warm years. Accordingly, in the coastal waters, plankton reproduction takes place in April, in the Arctic ones – in July-August and in the high Arctic ones (78-80ºN) – in September. More significant differences are registered in the anomalous warm years (2002-2006) when Calanoida development and specific structure directly depends on the latitudinal position and the ice extent of the Barents Sea. Often in September, in the southern stations, crustaceans reached Stage IV-V, while, in the northern ones, in a number of cases, their intensive reproduction could be observed (Orlova et al., 2007, 2008) giving rise to younger developmental stages. The grazing by fish also has a considerable impact on plankton abundance and biomass (Hassel et al. 1991; Orlova, Boitsov, Ushakov, 2004).

The preliminary analysis presented in this report shows great differences in biomasses in the Barents Sea area with the evident prevalence of their values in the west and coastal areas, where occurring separate patches with biomass in the range 10-29 g/m^2 (c.f. Figure 4.17).

North, in the Frantz Josef Land (FJL) area the biomasses were quite high (from 3-4 to 8-21 g/m^2). They were somewhat lower in the areas of the Persey Elevation (4-13 g/m^2) and the Zhelaniya Cape (6-9 g/m^2). In FJL, in the area between 79°00’-81°40’N, prevailing by abundance were the arctic species *Pseudocalanus minutus*, *Calanus glacialis* and *Metridia longa*, and *Calanus finmarchicus* only occurred in the western part of the area. However, on the whole, their abundance seldom exceeded, in total, 100 thousand ind./m^2 (Figure 4.18 A). In the west of the Persey Elevation, where the abundance of copepods was also low, to the north of 81°N, the arctic species predominated as before, but the abundance of *C. finmarchicus* was higher; it decreased to the east and *P. minutus* became predominant (Figue 4.18 B). Accordingly, in the east, the portion of that species was stable high, as that one of *M. longa*, and there were few *C. finmarchicus* and *C. glacialis* there (Figure 4.18 C).

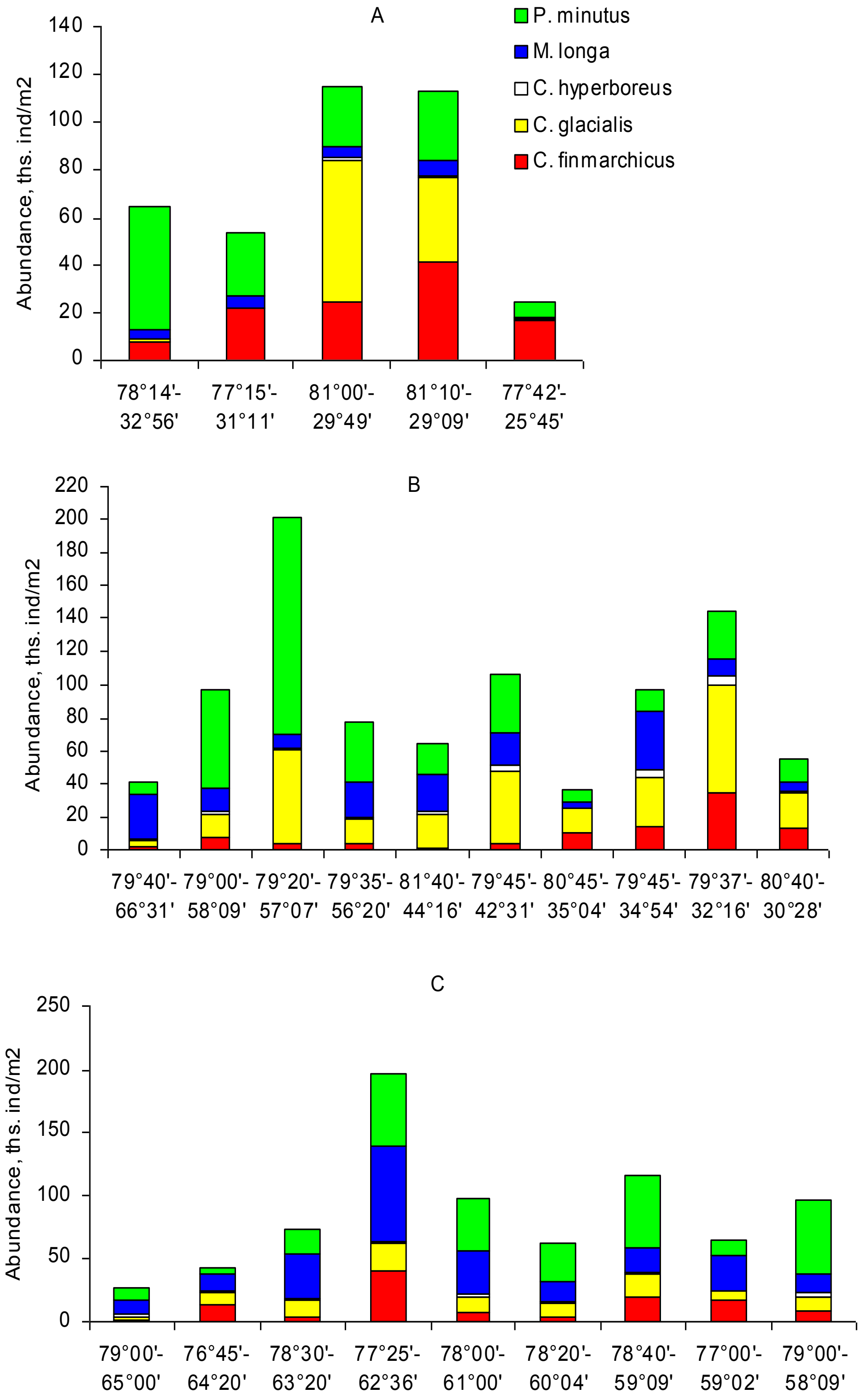

Figure 4.18. Abundance of zooplankton in the Persey Elevation (A), the FJL area (B) and the Cape of Desire area (C) in August-September 2007.

The age structure of abundant species showed the different phases of the life cycles. In the areas of *C. finmarchicus* prevalence, to the north of 78°N, its population primarily consisted of copepodites CIV (more seldom - CV), and, only to the south, the portion of juveniles CI-III increased (Figure 4.19 A,B). In the east, *C. finmarchicus* prevailed, except for more southward stations, where, on the contrary, there were more crustaceans CIV-V (Figure 4.19 C). Among the adults mainly females occurred, poor reproduction of this species was registered in FJL.

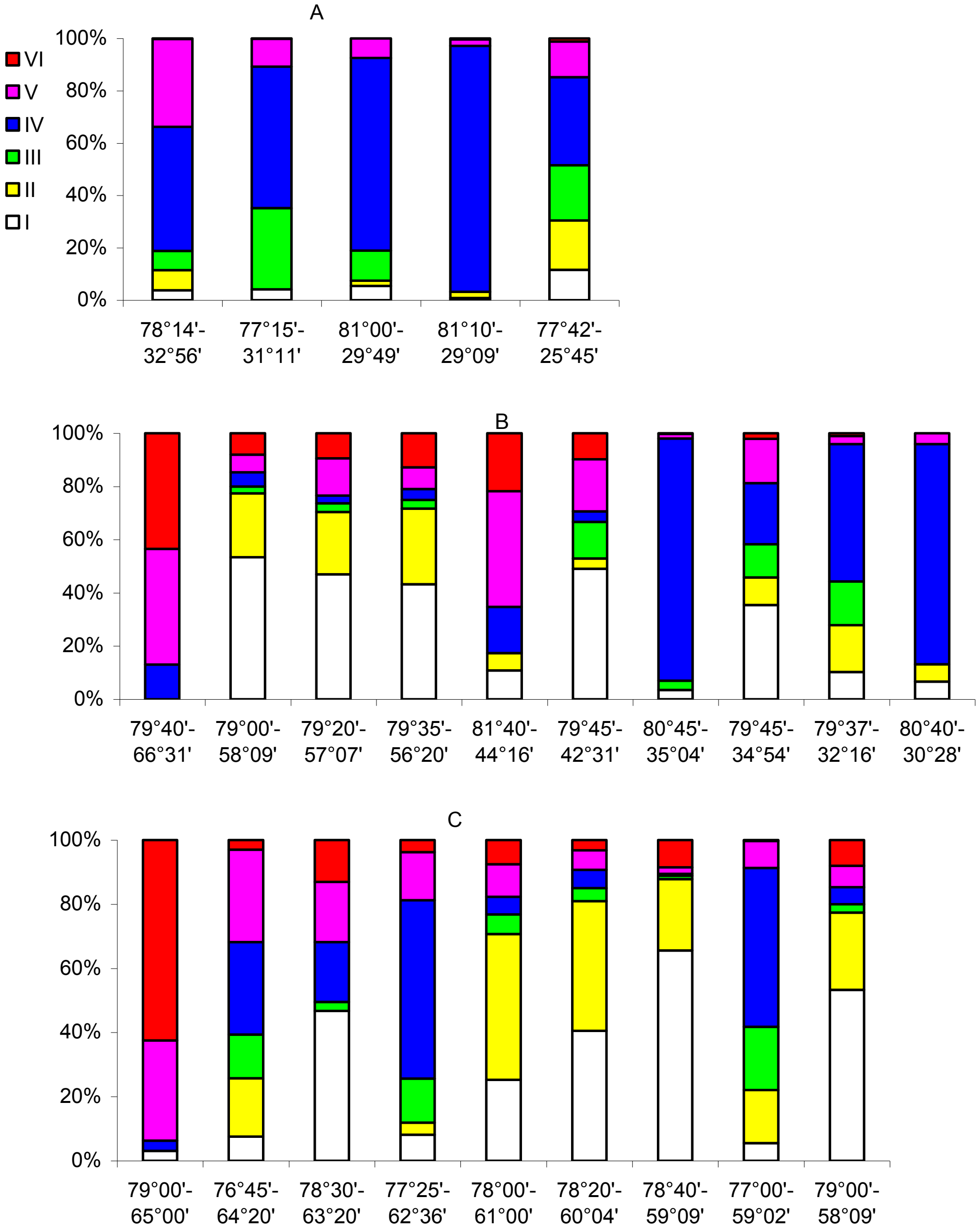

Figure 4.19. Stage composition of Calanus finmarchicus in the Persey Elevation (A), the FJL area (B) and the Cape of Desire area (C) in August-September 2007

In the western areas of FJL and the Persey Elevation, where the species abundance was maximal high, the population of *C. glacialis* was mainly represented by juveniles CI-III, the portion of which increased in the eastern direction (Figure 4.20 A,B). In most of the areas, overwintered crustaceans CIV (more seldom CV) were also present, and, in the most northward areas of FJL, as at the southern stations of the Persey Elevation, mature individuals (primarily females) occurred in great numbers. At the same time, in the north of FJL, the intensive reproduction of *C. glacialis* and *C. hyperboreus* was registered; the mass reproduction of *C. glacialis* was also observed in the east (59-61°E).

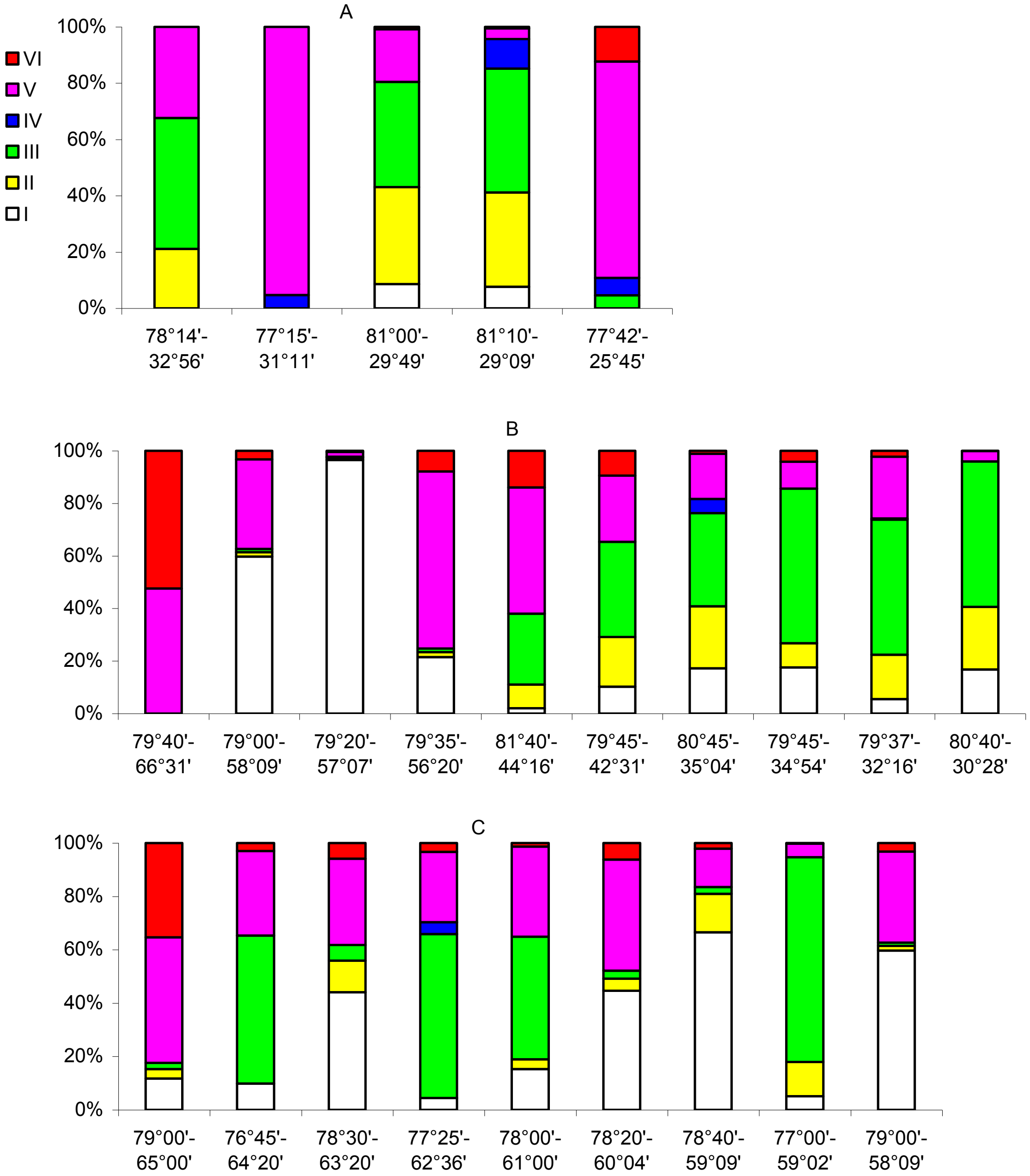

Figure 4.20. Stage composition of Calanus glacialis in the Persey Elevation (A), the FJL area (B) and the Cape of Desire area (C) in August-September 2007

In the north and northeast, the maximal values were mainly formed due to *C. glacialis* at stages III-VI accounting for to 50-60% of the total biomass. Alongside with that species, playing a leading part were *C. hyperboreus*, *M. longa*, as well as the representatives of Pteropoda (*Clione limacina*) and Sagitta. *C. finmarchicus* was less important, the biomass formed due to that species did not exceed 0.5-2.5 g/m^2. The biomass formed by the species varied at the high level (1.2-11 g/m^2) only in the west. Together with its biomass, those ones of Euphausiidae (0.2-0.6 g/m^2) and jellyfish (0.5-8.8 g/m^2) were quite high.

On the whole, the state of zooplankton in the Barents Sea in 2007 was highly affected by two important factors: the weakening of the total discharges of water in the North Cape Current, the northern branch of the North Cape Current and the Bear Island Currents compared to a normal situation, and with the very dynamical state of ice during summer period. Respectively, the first factor had a limiting influence on transportation of *C. finmarchicus* from the Norwegian Sea and, combining with the second factor, on the pattern of its distribution in the sea area. Besides, it has been shown in a recent paper (Orlova et al., 2008), with a high rate of ice retreat in the Barents Sea in the north (2004, 2006), dominating plankters were the arctic species (*C. glacialis*, *P. minutus*) playing the leading part in biomass formation. When ice retreats slowly (2002, 2005), *C. finmarchicus* is gradually accumulated and its role in biomass formation significantly increases. Plankton structure, level and character of biomass distribution in the Barents Sea in 2007 support this regularity.

4.4.1.1 Calanus Composition at Fugløya-Bjørnøya Transect

The transect Fugløya-Bjørnøya (FB) is situated at the western entrance to the BS. In 2007, FB section was covered 5 times, in January, March, June, August, and in November. The stations at this transect are taken at fixed positions and but the coverage may vary each year from 5 to 8 stations depending on weather conditions and available time. We have selected 4 stations from the FB section taken in different water masses (coastal, Atlantic, mixed Atlantic/Arctic). Samples at each station were analyzed for species composition of all zooplankton present. Copepods contribute largely to zooplankton biomass and in general *Calanus* species are by far the most dominant of all mesozooplankton in the Barents Sea. In this report we present the species abundances of the three dominant *Calanus* species, *C. finmarchicus*, *C. hyperboreus*, and *C. glacialis*. In addition, we have examined the occurrence of *C helgolandicus* in the March and August samples. *Calanus helgolandicus* is quite similar in appearance to *C. finmarchicus*, but is a more southerly distributed species (related to warmer waters) with a different spawning period. This species has in recent years been more frequently observed in the North Sea and southern parts of the Norwegian Sea (Svinøy transect). With the warming conditions, *C. helgolandicus* is expected to advect into more northerly areas with the Atlantic and Coastal currents. One of the main aims of this project is to examine the impact of climate conditions on the species composition of zooplankton and how this may affect the higher trophic levels.

Among the three *Calanus* species, *C. finmarchicus* is by far the most dominant (90 000 ind. m^{-2}). The development of *C. finmarchicus* in the western part of the Barents Sea starts in April close to the coast and progresses in time northwards along the section (Figure 4.21). On the two northernmost stations (at 73°30’ and 74°N), the recruitment of *C. finmarchicus* particularly evident in June, August and November, with very low abundances observed in the winter months. The cold-water species, *C. glacialis* was found in rather low abundances in the coastal and Atlantic waters (70°30’ and 72 °N). The highest abundances of the species (10 000 ind. m^{-2}) was observed at the shallow station taken at 74 °N, reflecting the presence of Arctic waters at this location. The pattern in development of *C. hyperboreus* is somewhat unclear with high abundances in June (72°N) and in November (74°N). The abundance of *C. hyperboreus* was generally much lower (650 ind. m^{-2}) compared to *C. finmarchicus* and *C. glacialis*.

Samples from 8 stations in March and in August 2007 were examined to separate *C. helgolandicus* from *C. finmarchicus*. *C. helgolandicus* was observed only in two stations taken in March. The ratio of *C. finmarchicus* to *C. glacialis* varied with 9:1, and 6:4 at these stations taken at 72ºN and 74ºN respectively. This work will continue in the coming years and we particularly intend to analyze historical samples to establish a baseline for future comparison. These investigations will be carried out in collaboration with the Norwegian and North Sea plankton investigations. From 2008 onwards the species composition data will be exchanged with PINRO.

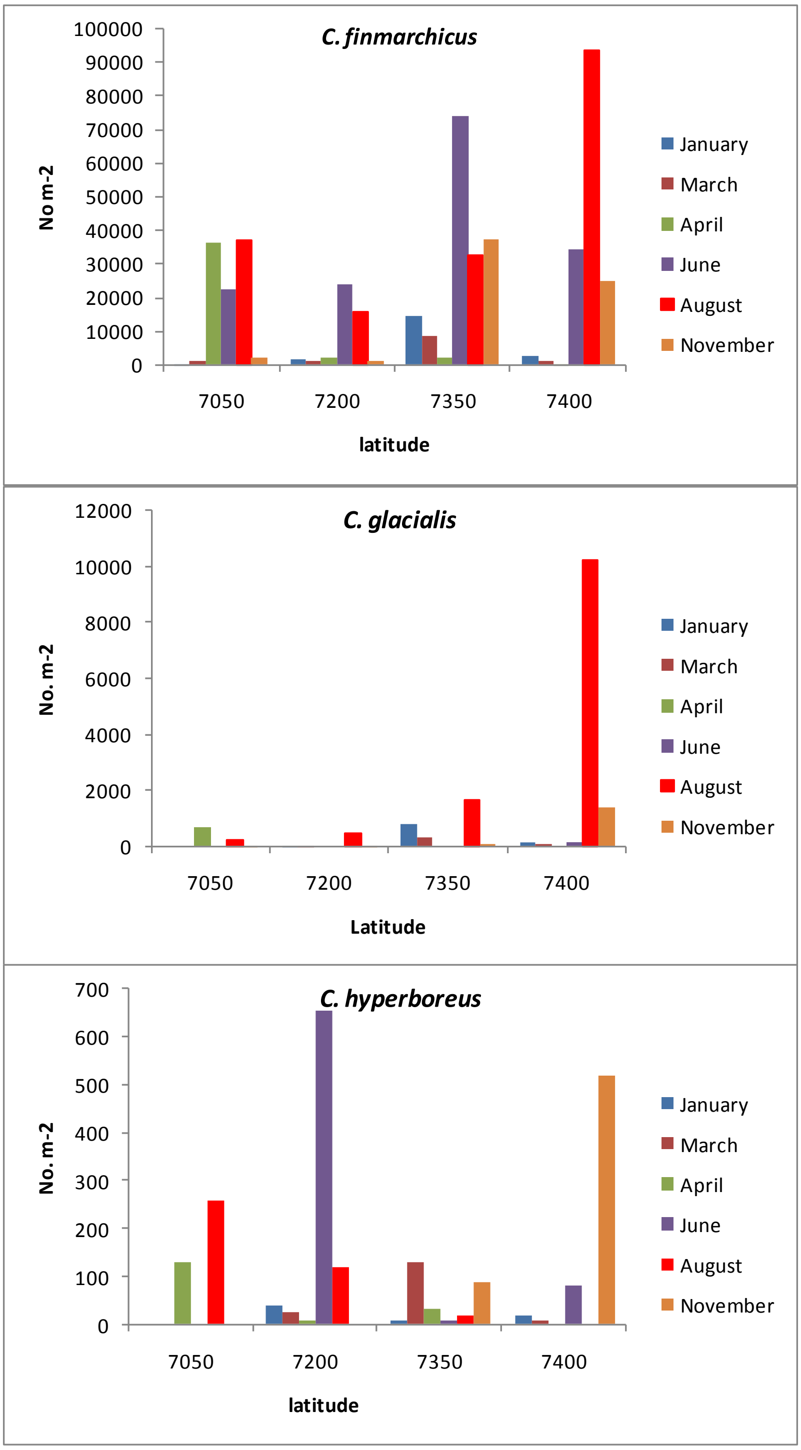

Figure 4.21. Development of copepod abundance along the transect Fugløya-Bjørnøya 2007.

4.4.1.2 *Macroplankton*

During the winter research survey samples were collected for estimation of pre-spawning stock of euphausiids in 2007 in the northwestern and western Barents Sea, where the arctoboreal species *Thysanoessa inermis* dominated. By the end of 2007, in the northwest, the abundance of euphausiids was lower by 58% (2.4 times) than the values obtained by the results of the winter research survey in 2006 (Figure 4.22). In the western area, the number of euphausiids remained at the previous level.

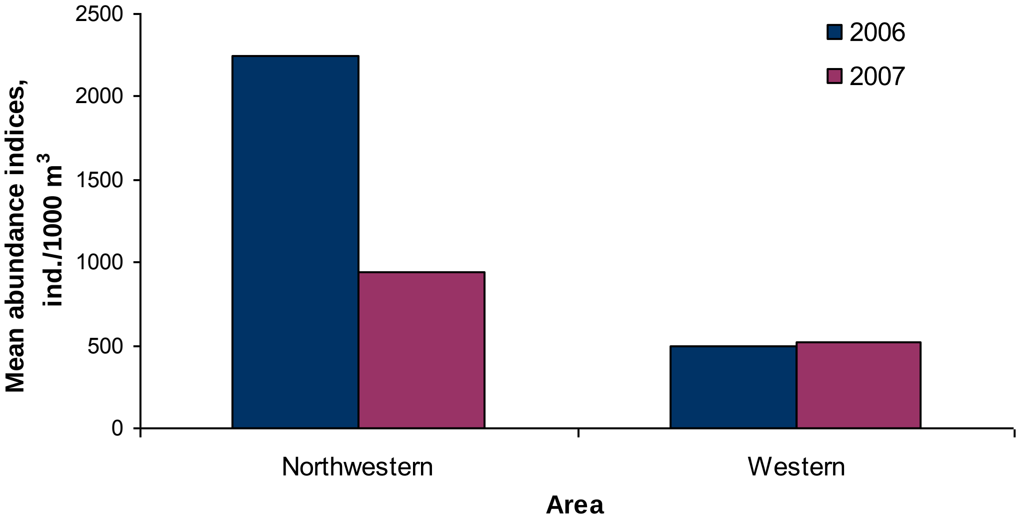

Figure 4.22. Mean abundance indices of euphausiids in northwestern and western areas of the Barents sea in autumn 2006 and 2007.

In 2007, as in 2006, the abundance of euphausiid crustaceans was higher than the long-term means (Figure 2.13). In the north-west, despite the total reduction in abundance, the maximal concentrations of euphausiids (1000-6500 ind./1000 m^3) were found in the South Cape Deep, the Hopen Island area, the eastern slope of the Bear Island Bank, the Kopytov Bank area (Figure 4.23), but, the abundance of euphausiids significantly fluctuated (from 2 to 6500 ind./1000 m^3). In the western sea, the high local concentrations of euphausiids (more than 1000 ind./1000 m^3) were registered on the Demidov and Nordkin Banks.

In the northwest, the portion of warm-water species *Meganyctiphanes norvegica* accounted for 3% (mean abundance – 32 ind./1000 m^3). The greatest concentrations were distributed on the west and south slopes of the Bear Island Bank (14 and 16%, respectively), in the Western Deep (7%), the central Elevation (3%), on the eastern slope of the Bear Island Bank (2.5%), as well as in the Kopytov Bank area (5%). According to the data obtained in November 2006, the abundance of that species equaled to about 40 ind./1000 m^3 (2%), in the northwestern fishing areas. As a whole, in the northwestern Barents Sea, the abundance of *Meganyctiphanes norvegica* has remained to be at the level of 2006.

In the western areas, the greatest relative abundance of that species was recorded on the Nordkin Bank, in the Murman Tongue and on the Rybachya Bank (30, 34 and 29%, respectively). In the west, the absolute and relative abundance was three times higher compared with 2006 (40 ind./1000 m^3 and 8%) and amounted to 117 ind./1000 m^3 or 23% of the total euphausiid abundance.

On the whole, the trend towards the stable growth of this species abundance during 2005-2007 (54 ind./1000 m^3 in 2007 against 25-40 ind./1000 m^3 in 2005-2006, respectively) has been observed. The increase in absolute abundance of *Meganyctiphanes norvegica* (1.5-5 times), as compared to 2006, was recorded on the Demidov, Finmarken and Nordkin Banks, the western and southern slopes of the Bear Island Bank, in the Kopytov Bank area.

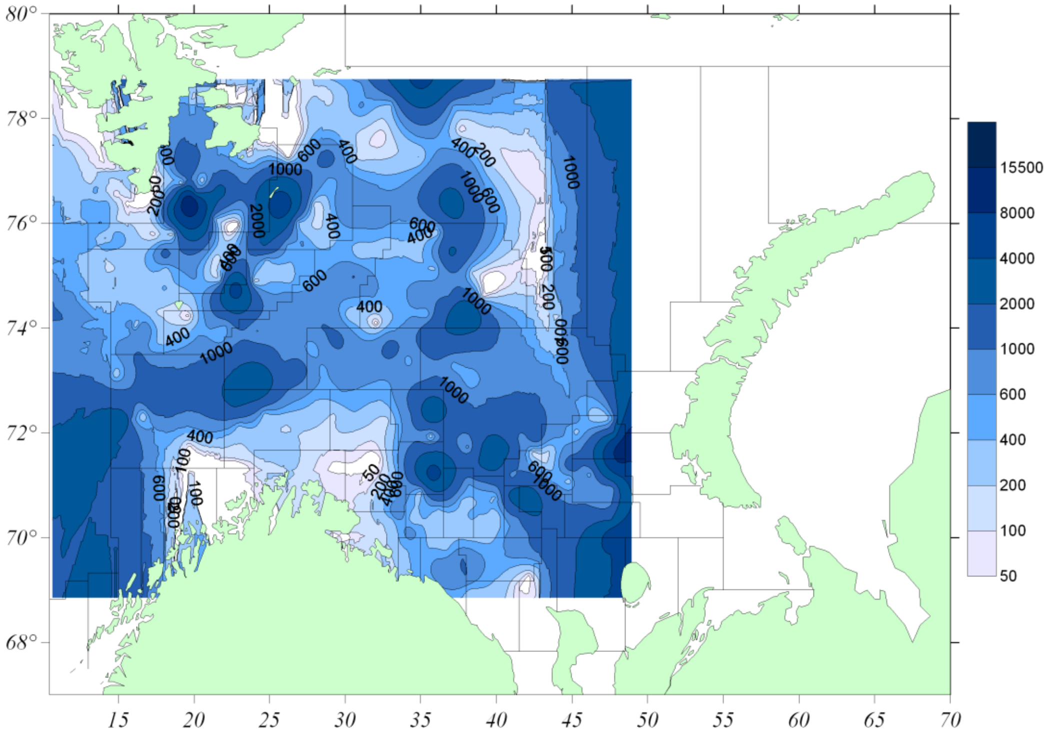

Figure 4.23. Abundance of euphausiids close to the bottom (ind. / 1000 m^3) in 2007.

4.4.1.3 Gelatinous zooplankton

In Figure 4.24 is given the distribution of gelatinous zooplankton caught by the pelagic trawl in 2006 and 2007. It is observed for 2006 that a higher concentrations of gelatinous zooplankton is mainly found south of approximately 76º30'N. In 2007 there seems to be a higher abundance of gelatinous zooplankton, particularly evident between longitudes 30-40ºE, even extending further north then what was observed in 2006. The data should be interpreted with caution as they are the first of its kind. The majority of trawl hauls are standardized stepwise hauls conducted in the 40-20-0 m depth interval and catches are corrected for time of trawling. The catches reflect the occurrence of the larger Schypozoan medusa probably of the genus *Aurelia* and *Cyanea*, while other smaller "jellyfish" are probably not well caught in the pelagic trawl. The occurrence of *Ctenophora* cannot be verified the way the data have been extracted and compiled, but larger and more robust forms are often caught also in this type of gear, particularly if they are abundant. For *Ctenophora* and smaller "jellyfish" catches in the WP2 net and the Mocness should be compiled for future comparisons.

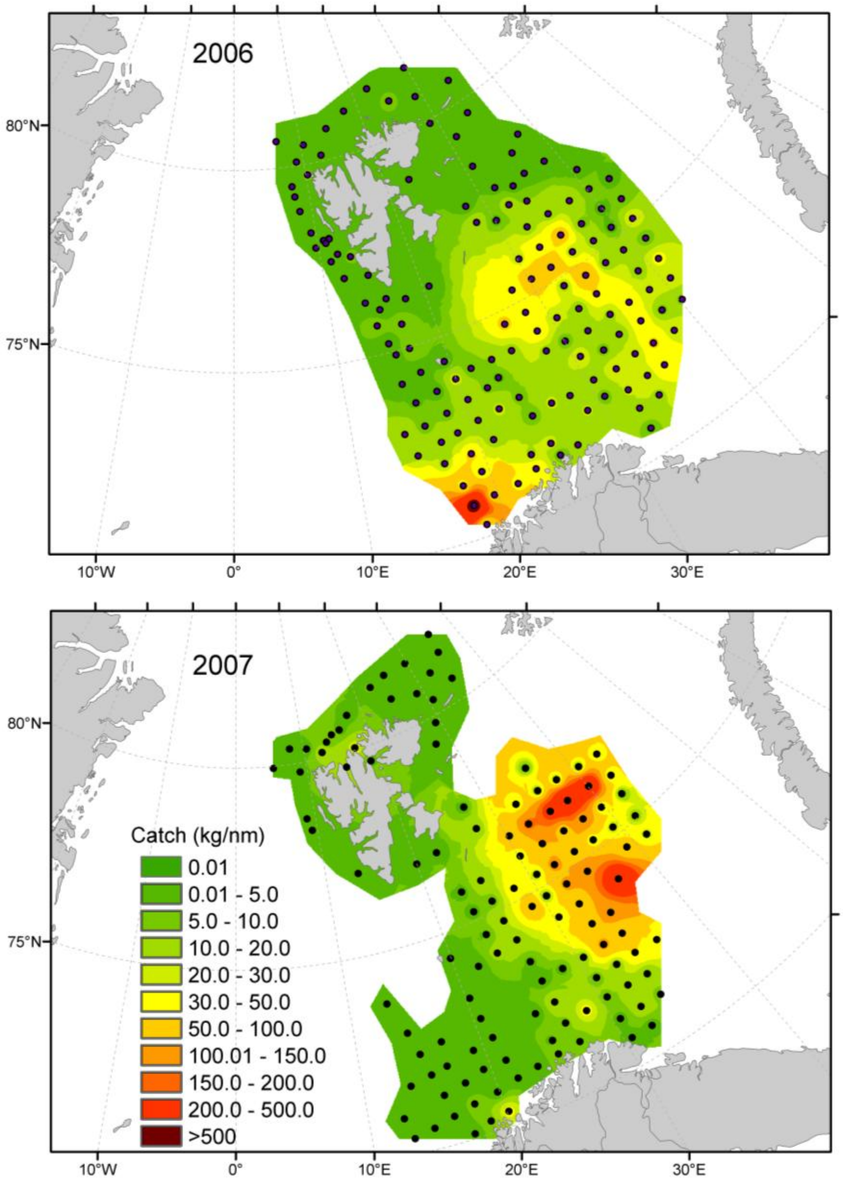

Figure 4.24. Distribution of gelatinous zooplankton based on catches from the pelagic Harstad trawl in 2006 (upper panel) and 2007 (lower panel). Numbers are kg·nm^{-1}.

4.4.2 Expected situation

Taking into consideration the hydrographic conditions and the long-term dynamics of zooplankton development, the spawning of the main zooplankton organisms (copepods and euphausiids) in 2008 in the southwestern areas of the Barents Sea is expected to start in the middle of April. Having overwintered, these groups of crustaceans, along with the warm-water species transported from the Norwegian Sea, will contribute to the establishment of zones with high density of zooplankton in the northwestern and western sea areas. As a result the food supply for pelagic predators will probably be sufficient. In late May-June euphausiids will descend to the bottom layers where they are more available as feed for adult cod.

It is expected that 2008 will be similar to 2007 with regard to the distribution and periods when fish feeding areas by plankton are being formed. Hence, it will most probably provide good feeding conditions for capelin, herring and juvenile fish. However, a considerable uncertainty exist with respect to the recovery of capelin, the development of the blue whiting and herring stocks and how this might influence zooplankton growth and abundance.

The average zooplankton biomass measured in August–September 2007 (7.13 g dry weight/m^2) was slightly lower than the long-term mean (7.14 g dry weight/m^2), and has dropped significantly compared to 2006 (8.6 g dry weight/m^2). Atlantic water masses contain the highest biomass, stressing the importance of advective transport of zooplankton from the Norwegian Sea, and the favourable higher temperatures in these waters influences the central western part of the Barents Sea. The adult capelin stock was reasonably low in 2006 but has considerably increased in 2007. Other plankton consumers like juvenile cod, capelin, haddock and redfish are important, but particularly young herring, which has been very abundant the last few years, certainly influence zooplankton biomass. Additional species such as blue whiting and sandeel seem to maintain their distribution range in the Barents Sea, hence their predation pressure on zooplankton will not change significantly. The average zooplankton abundance in 2007 suggests that the condition for local production might be less favorable for 2008. The total production will probably depend largely on the magnitude of zooplankton advection from the Norwegian Sea, although it should be noted that mesozooplankton abundance and biomass here, have been declining over several years now. However, the large increase in the capelin stock from 2006 to 2007 (2 to 4 million tons respectively) is probably the main factor causing the drop in average zooplankton biomass. On the other hand it cannot be ruled out that impact of grazing by gelatinous zooplankton could be partly responsible for the decline in zooplankton biomass. It is puzzling that the area with low mesozooplankton abundance in the central part of the Barents Sea in 2007 seems to coincide with areas of higher gelatinous zooplankton abundance. A high abundance of gelatinous zooplankton in 2007 could favour a similar situation for 2008, and an increased uncertainty with respect to calanoid copepod development and production.

4.5 Benthos

By L.L. Jørgensen (IMR), N. A. Anisimova (PINRO), P. A. Liubin (PINRO)
and I. E. Manushin (PINRO)

4.5.1 Current state

By-catch investigations indicate that the current distribution of mega-benthos in the Barents Sea is highly variable from area to area but also seem to vary from year to year (Figure 4.25). The biomass-hotspots, recorded every year, are located at “shallow water areas” as the Tromsø Flake (mainly sponges), on the Spitsberg Bank, the Olga Strait, Goose Bank and Novaya Zemlya Bank.

Figure 4.25 indicates that there might have been a spatial and temporal increased in bottom animals (weight) from 2006-2007 in south eastern Barents Sea. On the other hand might there have been a reduction in the Hopen Deep.

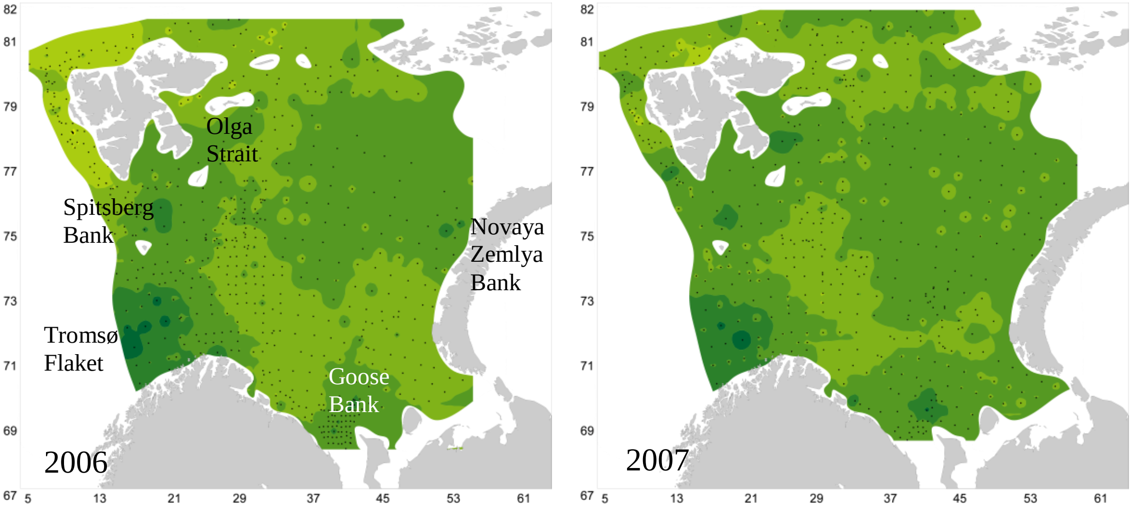

Figure 4.25. Bottom fauna by-catch in August-September 2006 and 2007. The dots in the background are by-catch stations. Dark green are weight maximum while light green are weight minimum.

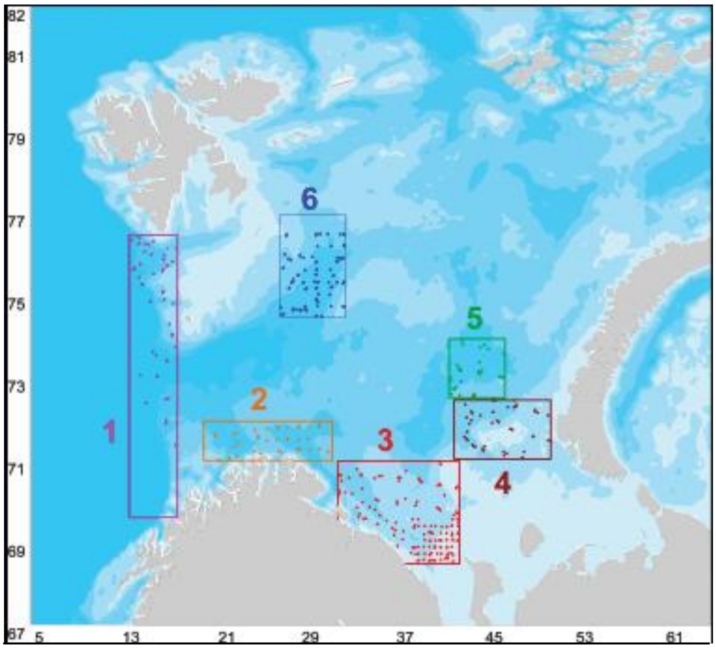

Figure 4.26. Established long term, monitoring areas. Area 1: Western slope. Area 2: North Cape Bank. Area 3: Kola coast. Area 4: Goose Bank. Area 5: Shtokman field. Area 6: Hopen deep.

In the newly established long term monitoring areas (Figure 4.26, details can be found in section 3.6) all stations were analysed within each subarea before they were summarized and a mean value calculated. The validity of the 2005-data is discussable because the method was still under development among the Norwegian boats. But the preliminary results (Figure 4.27) indicate that there has been a steady increase in benthos-biomass from 2005 to 2007 in all areas, except area 1 (the Western slope) and 6 (the Hopen deep).

In area 1 (the western slope) it was mainly a reduction in the catch of sponges (Table 4.4) which caused the drop in weight. In area 6 (the Hopen Deep) it might have been a reduction in the sea star catch (several species of sea stars) which night have caused the decrease. The increase in area 2 (North Cape Bank) and area 3 (Murmansk Coast) might be related to the still increasing population of red king crab *(Paralithodes camtschtica)*. In area 4 (Goose bank) an increasing population of the snow crab (*Chionoecetes opilio*) might have been the reason for the increasing weight of by-catch taken in this area. Increasing by-catch of several taxa (prawns, seastars and sea cucumbers) are most probably the reason for the result in the Shtokman field.

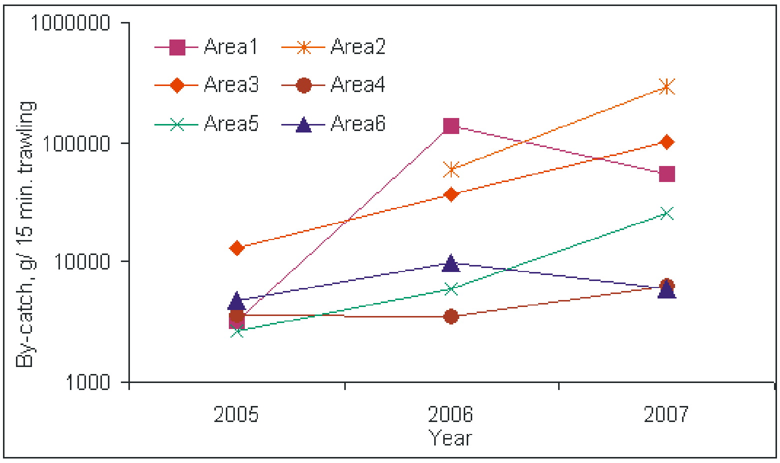

Figure 4.27. By-catch in gram wet weight (mean value of all stations -15 minuets trawling- analysed within each monitoring area) for 2005-2007. Area 1: Western sloope, area 2: North Cape Bank, area 3: Murmansk coast, area 4: Goose Bank, area 5: Shtokman field, area 6: Hopen deep.

Table 4.4. The top five dominating by-catch bottomtaxa in weight per 15 min. trawling per year and per area.

		2005	**2006**	**2007**
Area 1	Anthozoa g. sp.	0	586	28
Western Slope	Asteriidae g. sp.	283	826	155
	Echinoidea g. sp.	0	277	5
	Holothuroidea g. sp.	0	561	414
	Porifera g. sp.	425	134593	53866
Area 2	Anomura g. sp.	0	40	1997
North Cape Bank	Anthozoa g. sp.	0	1045	26
	Asteriidae g. sp.	0	573	1211
	Paralithodes camtschaticus	0	195	2786
	Porifera g. sp.	0	58094	283036
Area 3	Cucumaria frondosa	6	0	286
Murmansk Coast	Geodia barretti	0	382	0
	Hormathia digitata	0	63	159
	Paralithodes camtschaticus	12692	35878	100869
	Porifera g. sp.	0	442	14
Area 4	Chionoecetes opilio	85	364	493
Goose Bank	Ctenodiscus crispatus	19	249	714
	Cucumaria frondosa	348	0	1401
	Natantia g. sp.	0	1287	0
	Strongylocentrotus sp.	2417	97	0
Area 5	Ctenodiscus crispatus	210	468	3665
Shtokman Field	Gorgonocephalus arcticus	0	0	1818
	Molpadia borealis	0	0	8388
	Sabinea septemcarinata	698	590	2212
	Varia indet.	5	2	1656
Area 6	Asteriidae g. sp.	0	2180	1316
Hopen Deep	Ctenodiscus crispatus	1230	2044	405
	Icasterias panopla	790	384	93
	Molpadia borealis	10	440	20
	Polychaeta g. sp.	16	463	2124

4.5.2. Expected situation

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

We might expect more fluctuation in the biomass distribution of the benthic communities as observed from 2006 to 2007 (Figure 4.25). In particular datasets, referred in Wassmann et al (2006), from 1924-1932 and 1968-1970 seems extensive enough to examine community change for the entire Barents Sea soft-bottom habitat. Wassmann et al (2006) conclude that biomass distribution clearly shows differences between the two periods. Although the relative locations of high biomass generally correspond between them, the overall magnitude of biomass was reduced by 60% in the late 1960´s compared to the late 1920´s. These studies also describes that regular sea temperature measurements conducted along the Kola Transect since the beginning of the 20th century indicate that the late 1960´s was a particularly cold period, compared to the 20th century average temperature. While one Russian work attributes the decrease in benthic biomass in the 1960´s to the cold water temperatures, another Russian work suggest a more complex relationship where fluctuation in biomass are more strongly related to direct anthropogenic disturbance, in form of intensity of bottom trawling, than to temperature fluctuations.

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

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

4.6 Shellfish

By J. Sundet (IMR), C. Hvingel (IMR), P.A. Liubin (PINRO), V. A. Pavlov (PINRO) and M.A. Pinchukov (PINRO)

4.6.1 Northern shrimp (*Pandalus borealis*)

4.6.1.1 Summary

- Mortality: The fishing mortality has been below the upper limit reference (F_{lim}) throughout the exploitation history of the stock. The risk that F exceeded F_{lim} is estimated at about 2% for 2007. ‘The stock is harvested sustainably’ (ICES Advice 2007).
- Biomass: Indices of stock size have increased from 2004 to 2006. A decrease of 18% was observed from 2006 to 2007. The estimated risk of stock biomass being below B_{msy} at the end 2007 was 3%, but less than 1% of being below B_{lim}.

- State of the Stock: The stock biomass estimates has varied above its MSY level throughout the history of the fishery. Biomass at the end of 2007 is estimated to be well above B_{msy} and fishing mortality well below F_{msy}. 'The stock has full reproductive capacity' (ACFM 2008).

4.6.1.2 The fishery

A multinational fishery exploits the shrimp stock in the Barents Sea. Landings (Figure 4.28) peaked at about 130000 t/yr in the mid 1980s. During the recent decade catches have varied between 28 000 and 83 000 t/yr – 70-90% of these were taken by Norwegian vessels and the rest by vessels from Russia, Iceland, Greenland and the EU. In 2007 total landings amounted to about 30 000 tons (Hvingel and Thangstad 2007).

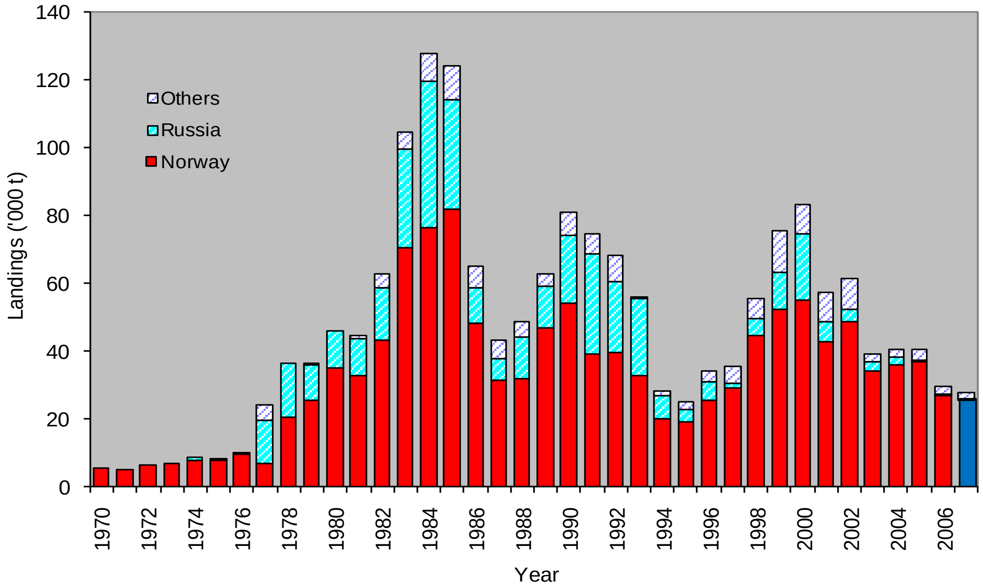

Figure 4.28. Total landings of Northern shrimp. The 2007 value is estimated based on partial data for the year. (From Hvingel and Thangstad 2007).

4.6.1.3 Research surveys

In 2007 survey catch of the shrimp ranged between 0.016 kg and 1.5 tons pr. haul. The data indicated that the stock decreased by 28% compared to 2006. The densest concentration of shrimp biomass was seen in the central parts of the Barents Sea and around Svalbard (Spitsbergen) (Figure 2.14).

4.6.1.4 Stock size and fishing mortality

A steep decline in stock biomass was noted in the mid 1980s (Figure 4.29) following some years with high catches (Figure 4.28) and biomass went below the optimum. Since the late 1990s the stock has varied with an overall increasing trend. The estimated risk of stock biomass being below B_{msy} in 2007 was 3%. The median fishing mortality ratio (F-ratio) has been well below 1 throughout the series (Figure 4.29). In 2007 there is a low 2% risk of the F-ratio being above 1 (Hvingel 2007).

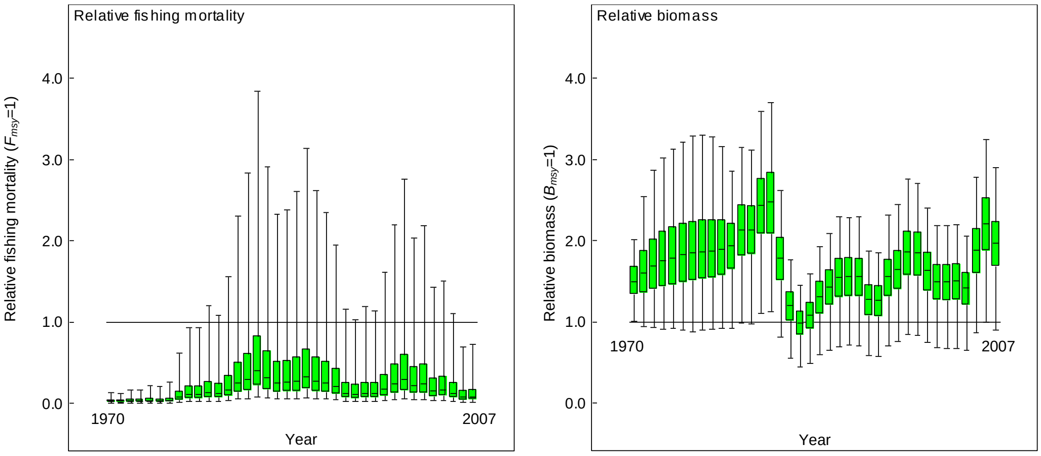

Figure 4.29. Estimated relative fishing mortality (F_t/F_{msy}) and biomass (B_t/B_{msy}) 1970-2007. Boxes represent inter-quartile ranges and the solid black line at the (approximate) centre of each box is the median; the arms of each box extend to cover the central 95 per cent of the distribution. (From Hvingel 2007).

4.6.2 Red king crab (Paralithodes camtschatica)

Maximum indices of the total and commercial stock of the red king crab in the Russian waters of the Barents Sea were estimated in 2003 (Figure 4.30). A gradual decrease in the abundance of the adult part of the population due to low recruitment and high natural and fishery mortality has been observed since 2004 and up to now.

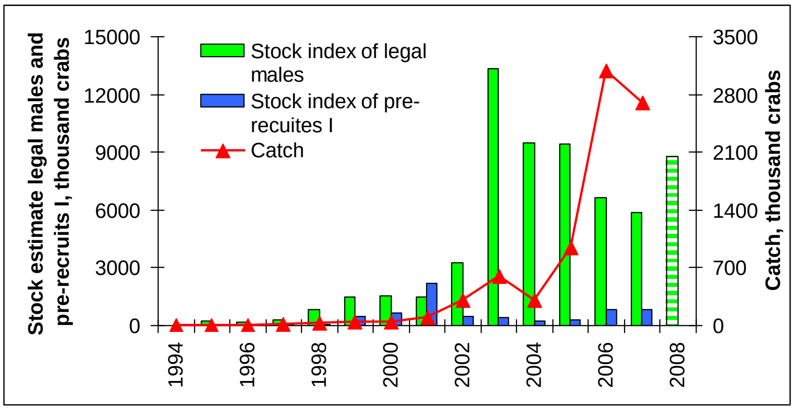

Figure 4.30. Dynamics of commercial stock, pre-recruit abundance and the catch of the Red King crab in Russian waters of the Barents Sea.

The highest abundance of pre-recruits I was recorded in 2001 when the index reached 2,200,000 individuals (Figure 4.30). During the period from 2002 to 2004 the index gradually decreased down to 231,000 individuals, with an increase to 809,000 during the period 2005-2006.

The commercial stock index in 2007 decreased by 1.1 times compared with 2006. Meanwhile, the pre-recruit I and recruit indices remained at the same level.

The distribution of red king crab in the eastern part of the Russian zone in 2007 was characterized by dense aggregations with more than 500 individuals per sq. km. In the Eastern

Coastal area and Murmansk shallow waters 96% of the total catch was taken. Commercial concentrations of crabs were not commonly observed in other parts of the habitat.

In the Russian part of the Barents Sea, the main harvesting areas of the crab are in off shore areas and the Russian catches of the Red king crab in 2007 was estimated to 2,7 x 10^6 individuals.

At present, the fishery for the red king crab is conducted under license and regulated by the following measures:

- it is prohibited to catch any females, and males less than 15 cm in carapace width, to use any fishing gear except for crab pots, to use crab pots with an inside mesh size less than 70 mm and to conduct fishery or any other exploitation of crabs during the reproduction period and molting season from the 15th of February to the 31st of August;

- a by-catch of crabs shall not exceed 10 individuals of any sex or size per 1000 kg of other species when fishing for other species

- by-catch of undersized crabs and females shall not exceed 25% of the total number of individuals when conducting commercial crab fishing;

- all crabs caught as by-catch shall be released into the sea with minimal damages regardless of their state.

Total stock (CL>70 mm) abundance were estimated for all areas of king crab distribution in Norwegian zone except for area Østhavet in 2007, and the estimates were at the same level as in 2006, about 4,3 million specimens. Legal male crab (CL> 137) stock was monitored in all Norwegian areas and estimated to be almost the same as in 2006; about 1 million specimens (Figure 4.30). The recruitment to legal male stock have been moderate or low recent years, but will increase significantly in 2008 and 2009 due to high numbers of prerecruit I and II in 2007 (Figure 4.31).

New legislations for the management of the king crab in Norwegian waters will be implemented in 2008, and preliminary information indicates that there will be commercial quotas both in male and female crabs. It is also proposed a two regime management of the crab where a certain geographical area will be kept as a “commercial area” where the crab is managed as a commercial fishing resource. Outside this area the aim will be to eradicate all crabs. The major part of the king crab stock in Norwegian waters is now limited to near coastal (< 12 nm) and fjord areas east of Hammerfest, but several recordings of single specimens have been done further west and more off shore (See Figure 2.15). A non-legislated fishery west of 26° E after 2006 have however, probably slowed down the spreading westwards.

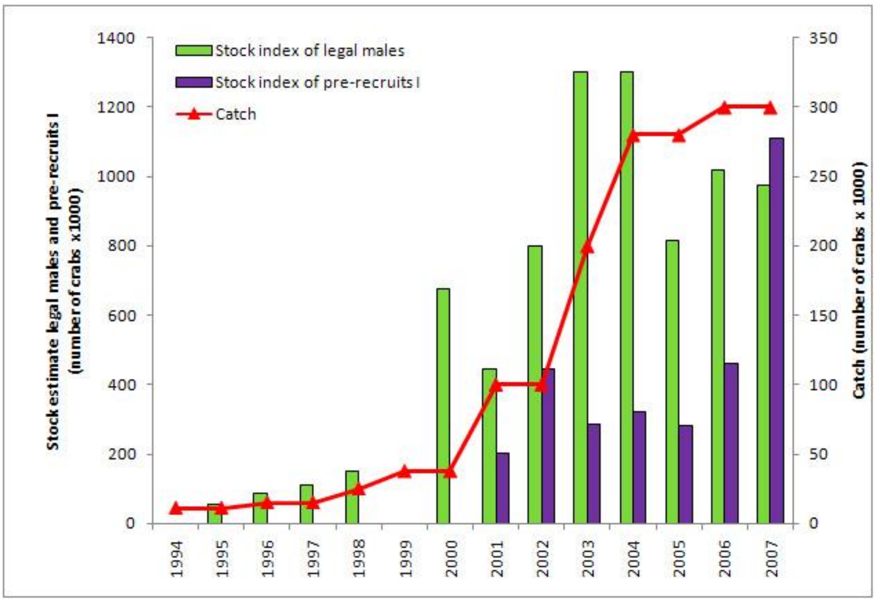

Figure 4.31. Stock index of legal male, Index of prerecruit I and total annual catch of red king crab in Norwegian zone in the period 1994 – 2007

Due to this new legislations one expect a set of new rules implemented in Norway for fishing king crabs in future.

4.6.3 Snow crab (Chionoecetes opilio)

In 2007 the first directed trawl survey of the Barents Sea snow crab stock was conducted (Figure 4.32). Investigated were 9 crabbing grounds over a 29859 km^2 area of in the eastern Barrens Sea outside the Russian 12-mile zone.

Indices for snow crab stocks were calculated using a random stratification method. Minimum landing size for snow crab in the Barents Sea was assumed to be 100 mm carapace width as in the Russian Far East.

The number of snow crabs in catches varied from 1 to 21 animals per hour trawling. Predominant in the catches were males accounting for 85% of the catches. The highest density of snow crab (60-100 individuals per km^2) was registered on the northern slope of the Goose Bank and in the Goose Land shallow waters.

According to results from the survey, the index of snow crab total abundance was estimated at 6.2 million individuals including 1.2 million legal size males and 0.2 million ovigerous females.

Data obtained from the ecosystem and targeted surveys showed that at present a considerable area in the Barents Sea contains snow crab. The densest snow crab concentrations are located in the eastern Barents Sea. The data suggest a large increase of snow crab abundance in this part of the Barents Sea in near future. In this context it makes sense to monitor the snow crab distribution and abundance.

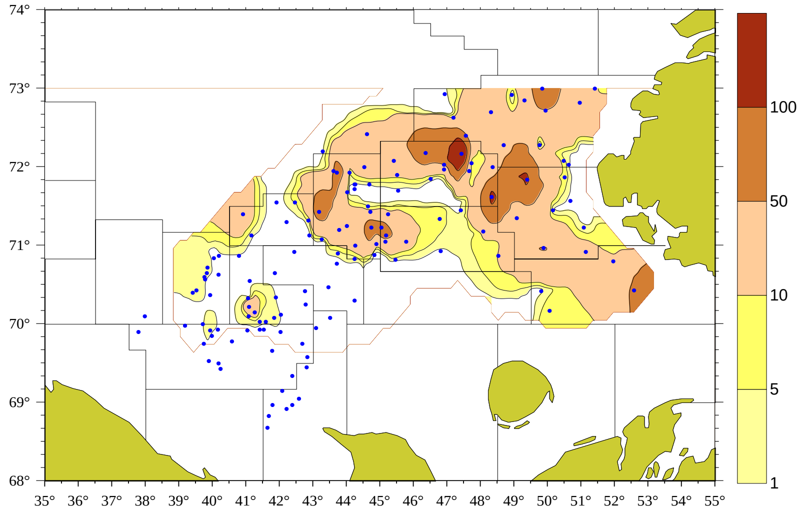

Figure 4.32. Distribution of snow crab total abundance (ind./km^2) in the Barents Sea in August-October 2007.

The snow crab has also been caught in the Norwegian part of the Barents Sea a (Figure 4.33). Both as bycatch in trawl surveys and in commercial trawl fishery, and in gillnets along the coast of Finnmark. These recordings are almost exclusive adult specimens indicating that the main areas of recruitment are in the eastern part of the Barents Sea, at the Goose Bank.

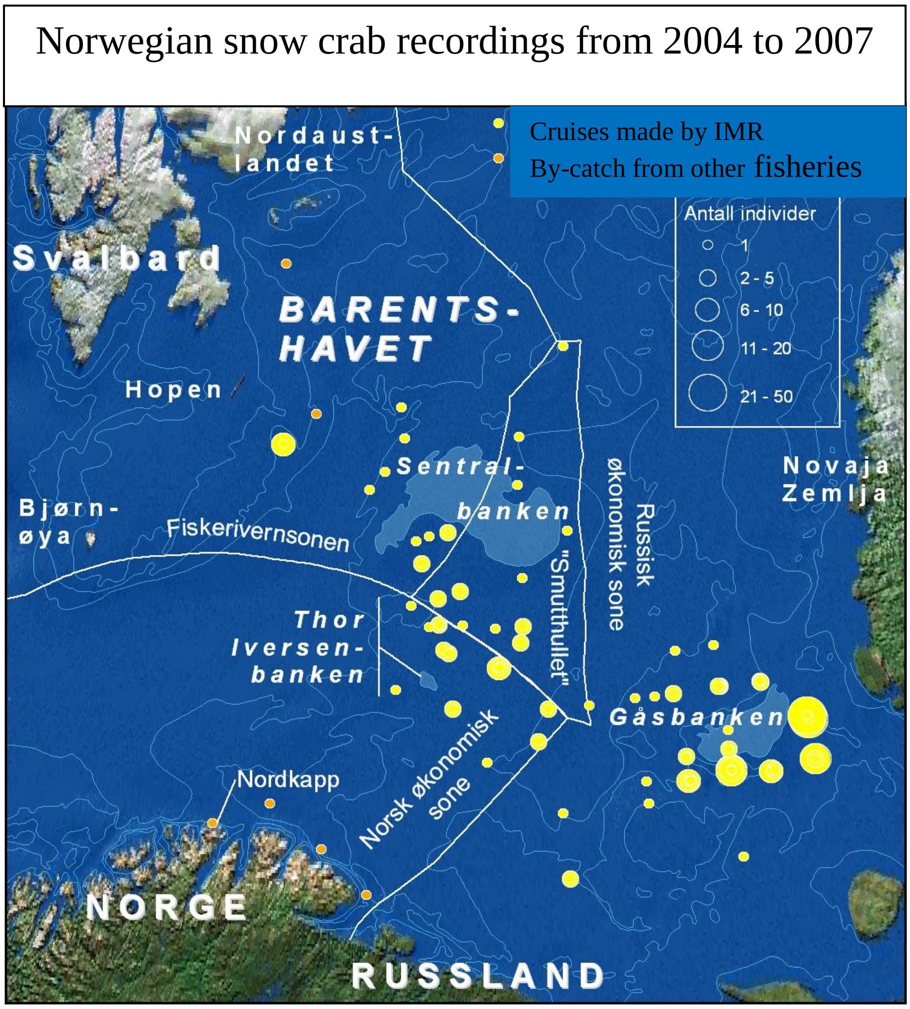

Figure 4.33. Norwegian catches of snow crabs (Chionoecetes opilio) in the period 2004 – 2007.

4.6.4 Iceland scallop (*Chlamys islandica*)

A survey was done by IMR in 2006 where the scallop beds north of Bear Island and at Moffen was studied (Figure 4.34). Since the beginning of the 1980s a small fishery for Iceland scallop have been performed on beds in coastal areas of Troms and Finnmark counties. These beds have been surveyed biannually and such a survey was carried out in 2007 to monitor a bed in Troms (Grøtøysund).

Figure 4.34. Map showing scallop beds at Bear Island and Moffen surveyed by IMR in 2006.
Stock status in the Svalbard area.

4.6.4.1 Stock status in the Svalbard area

Figure 4.35 show that there are quite high numbers of scallops caught at several dredge haul stations in both areas, particularly at Moffen. However, compared to historical catches the mean number of scallops caught per dredge haul were only about half of what it was in 1987 when the fishery started. The size and age distribution revealed that there seem to be good recruitment to both beds in recent years.

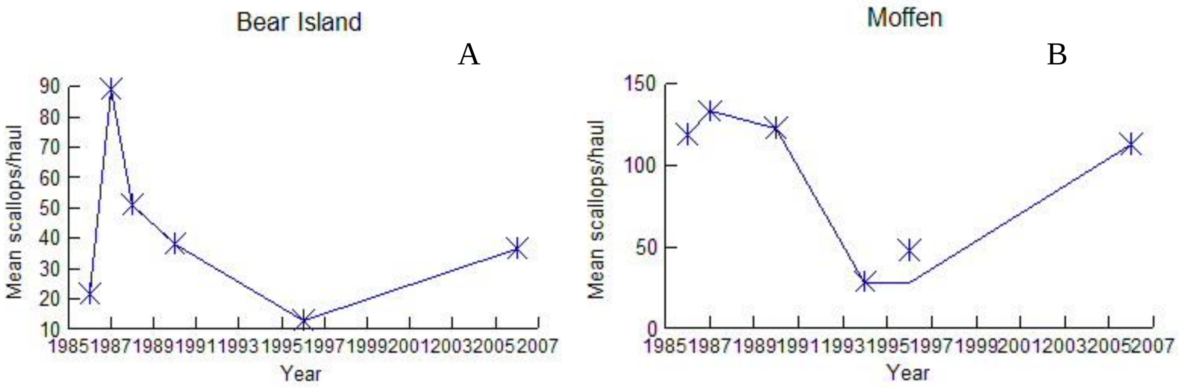

Figure 4.35. Mean number of Iceland scallops caught per dredge haul at Bear Island (A) and Moffen (B), on survey in different years.

4.6.4.2 Stock status in coastal beds

The survey in 2007 showed no major changes in stock status at the monitored bed in Troms compared to an investigation in 2005. There is relatively high abundance of commercial sized scallops in the area and the recruitment is good. There are two other Iceland scallop beds of commercial interest in coastal areas of Troms and Finnmark, and these will be monitored in 2008.

Russian studies on Iceland scallop in the Barents Sea in 2007 were carried out within the territorial waters of the Russian Federation off the Svjatoi Nos cape where the largest fishable settlement of scallops is located.

The fishable stock of Iceland scallop here was estimated over an area of 700 km^2 and amounted to 164,000 tons. When compared with 2006 the stock size in the same area has decreased by 40%.

Scallops in the size range 80-115 mm in shell height dominated in the commercial catches the average size of scallops in the beds were 62,8 mm. Scallops of non-commercial size (< 80 mm in shell height), constituted 50% of the total amount. The most numerous size group were scallops of 40-50 mm in shell height (approx. 4 years old).

A series of many years' observations of the status of the Svjatoi Nos scallop bed showed a sharp drop in the stock size starting in 2001 (Figure 4.36).

Primary causes for such a drop may be:

- Poor recruitment to the fishable stock due to decreased abundance of juvenile scallops in the beds in the period 1996-2005;
- High mortality of scallops due to fishing (fishing for scallops and bottom trawl fishing);
- Outbreak of a fungus disease that has been reported since 2003.

The major increase in abundance of juvenile scallops in the Svjatoi Nos bed was observed since 2005. Therefore, the fishable stock is expected to increase in this area thru 2011-2012, due to recruitment from the large 2005-2007 year-classes.

Catches of scallops were influenced by changes in the fishable stock. A sharp decrease in the catches was observed in 2002. Due to a considerable reduction in the fishable stock during the recent years it is recommended to close the fishery for Iceland scallop in 2009 until the stock improves.

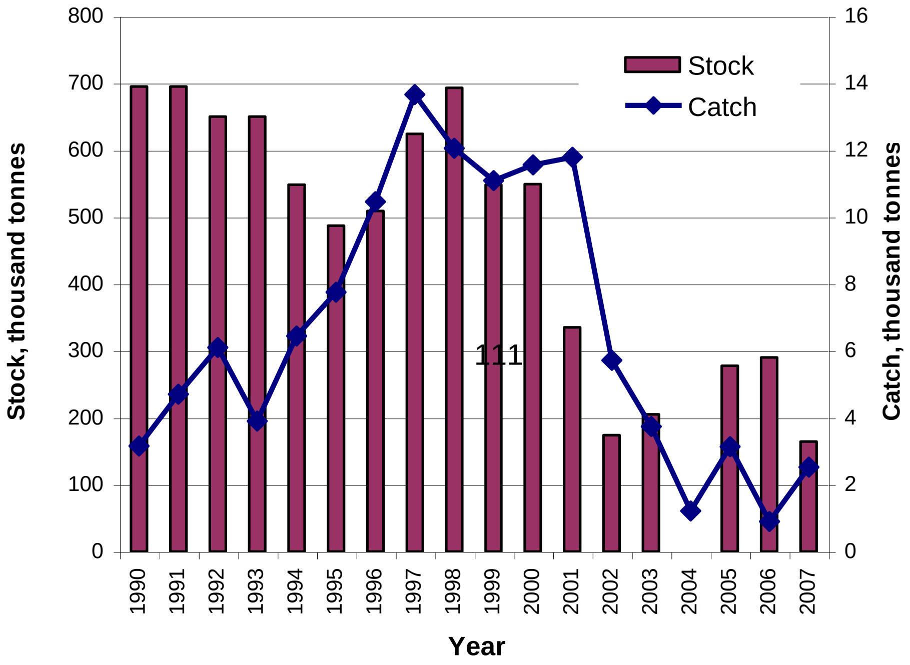

Figure 4.36. Fishable stock and catches of Iceland scallop in the fishable settlement off the Svjatoi Nos cape in the Barents Sea, 1990-2007.

4.7 Fish

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

4.7.1 Cod (*Gadus morhua*)

Based on the most recent estimates of spawning stock biomass (SSB, Figure 4.37), ICES classifies the stock as having full reproductive capacity. Based on the most recent estimates of fishing mortality, the stock is at present exploited with a fishing mortality equal to that intended under the agreed management plan. The SSB has been above B_{pa} since 2002. Surveys indicate that the 2004-2005 year classes are at above average while the 2006-2007 year classes are below average.

Fishing mortality was in the range 0.50-0.75 from 2001-2006, but dropped to 0.40(=F_{pa}) in 2007. This fishing mortality is within the range that will lead to high long-term yields (indicated to be in the F range 0.25-0.50).

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

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

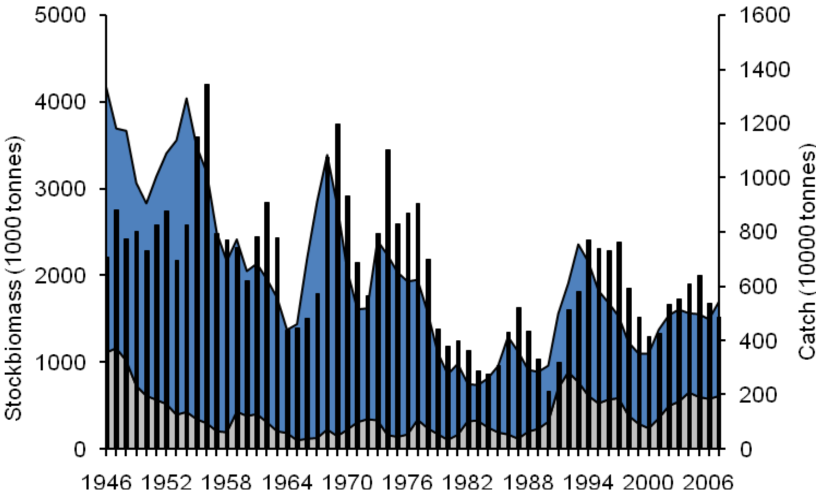

Figure 4.37. Northeast Arctic cod, development of spawning stock biomass (grey area), total stock biomass (age 3 and older, blue area) and landings (columns).

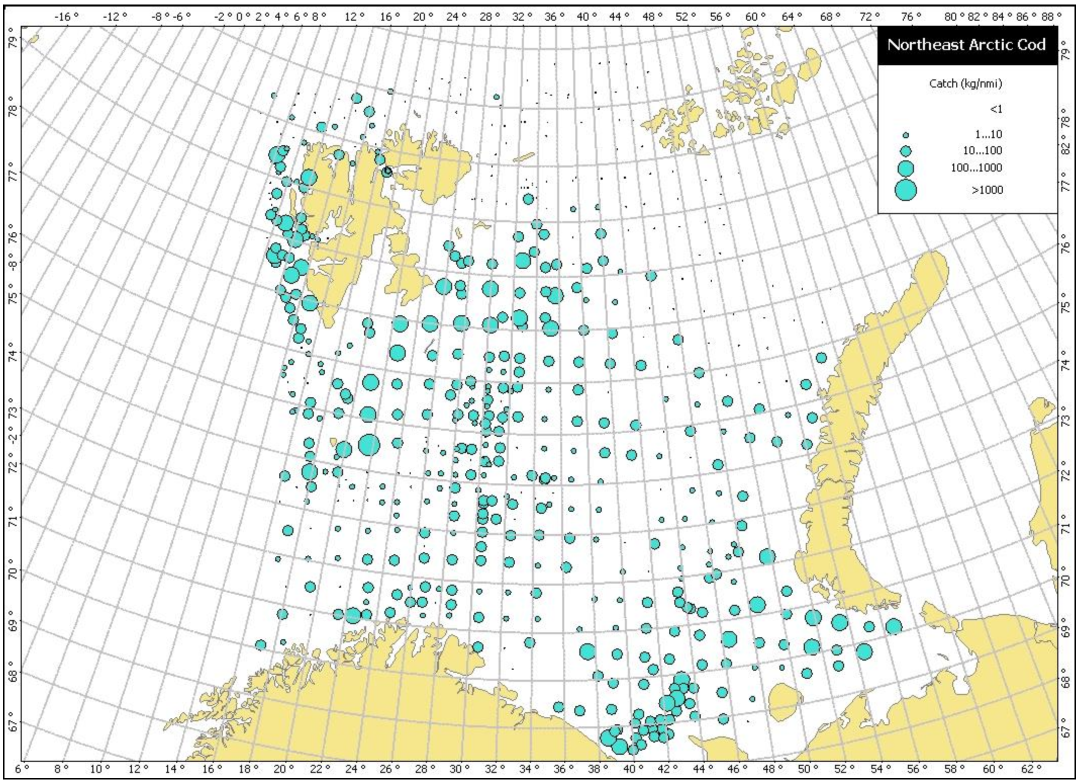

Figure 4.38. Distribution of cod, from ecosystem survey in August-September 2007.

4.7.2 Haddock (Melanogrammus aeglefinus)

Based on the most recent estimates of SSB (Figure 4.39), ICES classifies the stock as having full reproductive capacity. The fishing mortality has been close to F_{pa} in the last years. The assessment indicates that the spawning stock is at a high level, considerably higher than the long-term mean. Very strong year classes of 2004-2006 are expected to recruit to the fishable stock in 2008-2010, and thus the stock could well grow to the highest level observed in the time series, which go back to 1950.

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.

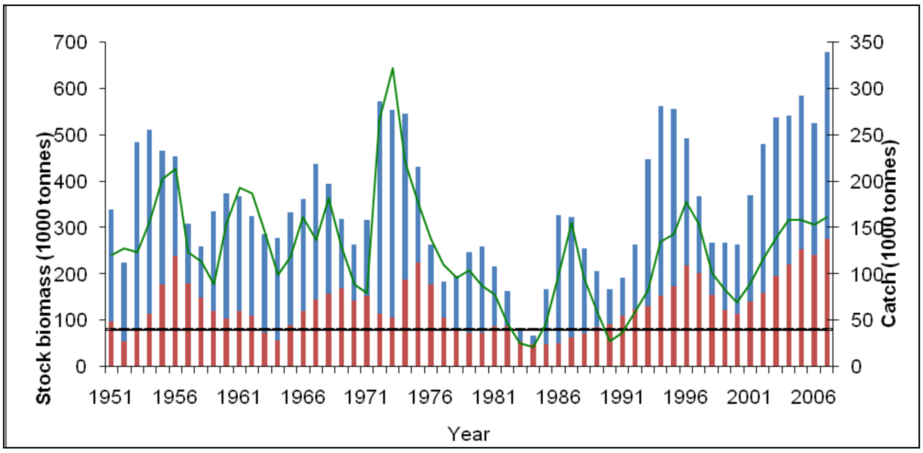

Figure 4.39. Northeast Arctic haddock, development of spawning stock biomass (red bars), total stock biomass (age 3 and older, blue bars) and landings (green curve).

4.7.3 Redfish (Sebastes mentella and Sebastes marinus)

4.7.3.1 Deep-sea redfish (Sebastes mentella)

Recruitment failure has been observed in surveys (Figure 4.40) for more than a decade. However, signs of improved recruitment of 0-group and juveniles are now seen in the Barents Sea. In this regard, it is of vital importance that the juvenile age groups be given the strongest protection from being caught as bycatch in any fishery, e.g., the shrimp fisheries in the Barents Sea and Svalbard area. This will ensure that the recruiting year classes can contribute as much as possible to stock rebuilding.

The only year classes that can contribute to the spawning stock in the coming years are those prior to 1991 as the following year classes are extremely poor. Several years’ protection and growth of these year-classes could have caused the higher abundance and densities recently encountered along the continental slope and pelagic in the Norwegian Sea. These year classes need to be protected as they offer the only opportunity of increasing the spawning stock for a number of years to come. This stock will not be able to support a directed fishery for several more years at least. Rather, it will be necessary to prevent the stock from declining further and to maintain measures to protect this stock from bycatch in other fisheries.

A directed pelagic fishery for deep-sea redfish (*S. mentella)* in international waters of the Norwegian Sea has developed since 2004. This fishery increased to record levels in 2006, and the total catch in 2006 was 33 thousand tonnes, the highest level since 1991. The catch declined to 19 thousand tonnes in 2007. There are uncertainties in the stock identity of the *S. mentella* caught in international waters of the Norwegian Sea, but it is most likely to belong to the same stock as the *S. mentella* found along the Norwegian coast and in the Barents Sea. In any case, the fishery for *S. mentella* in international waters of the Norwegian Sea is not in accordance with the precautionary approach.

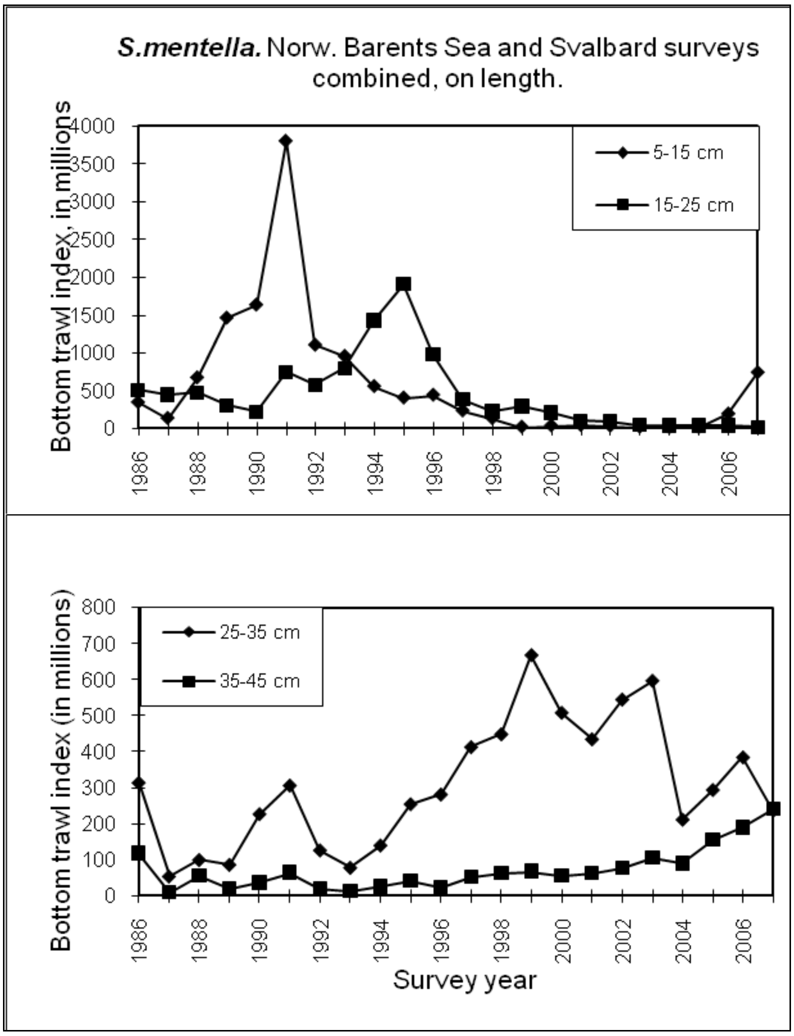

Figure 4.40. Sebastes mentella. Abundance indices (on length) when combining the Norwegian bottom trawl surveys 1986-2007 in the Barents Sea (winter) and at Svalbard (summer/fall).Upper panel - Small fish, lower panel - large fish.

4.7.3.2 Golden redfish (Sebastes marinus)

In the absence of defined reference points the state of the stock cannot be fully evaluated. Surveys (Figure 4.41) 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 Svalbard area. This will ensure that the recruiting year classes can contribute as much as possible to slowing the decline of the stock. Golden redfish (*S. marinus*) is currently being caught in a directed fishery and as bycatch in the pelagic trawl fisheries for herring and blue whiting in the Norwegian Sea. Better statistics on this bycatch, and regulations to prevent this continuing, are needed.

The catches have been around 7,000 t for the last 4 years, a level which seems to cause a continued decline of this stock.

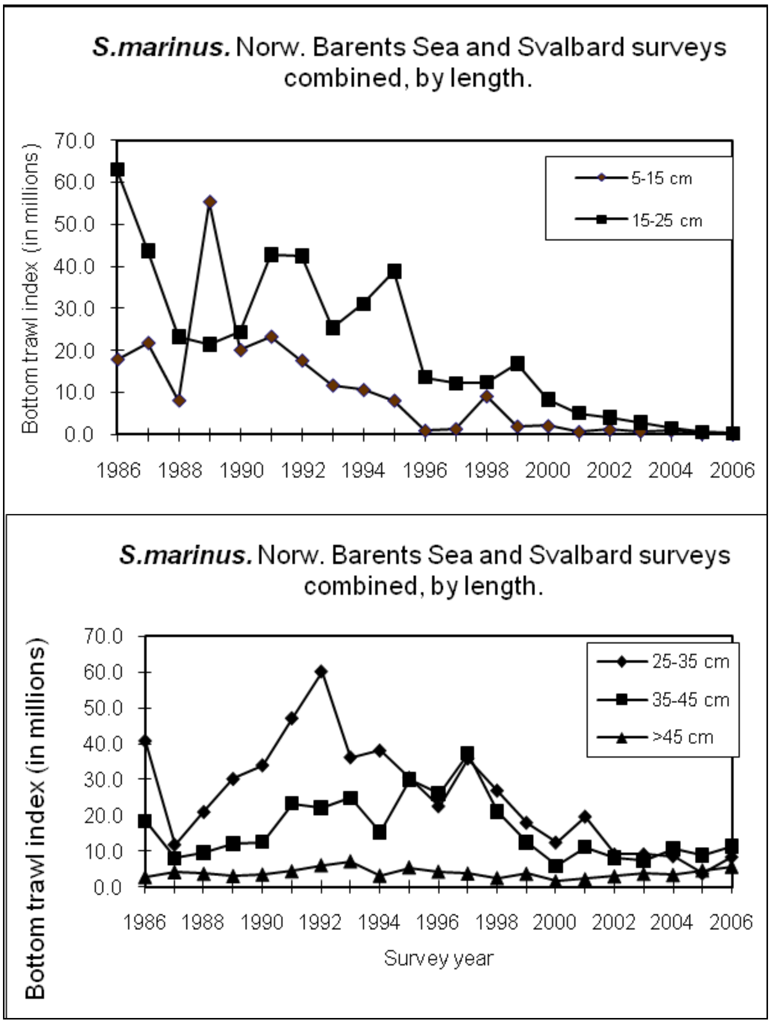

Figure 4.41. Sebastes marinus. Abundance indices (by length) when combining the Norwegian bottom trawl surveys 1986-2006 in the Barents Sea (winter) and at Svalbard (summer/fall).Upper panel: Small fish, lower panel: Large fish. Please note that the figure is not updated with 2007 numbers.

4.7.4 Greenland halibut (Reinhardtius hippoglossoides)

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

The stock has been at a low level for several years and it is a long-lived species, which can only sustain low exploitation. Indications are that the stock has increased in recent years both in a tentative assessment and in fishery independent surveys (Figure 4.43). During this period, catches in that fishery have been around 13 000 t (Figure 4.42). Given the state of the stock and the paucity of information, the fishery should not exceed 13 000 t until better information is available and firm evidence of a larger stock size has been obtained. In 2004-2006, catches were about 19 000 t, but declined to about 15 000 t in 2007.

The assessment is uncertain due to age-reading problems and lack of contrast in the data. The age-reading issue is being addressed and should be resolved in future years, but corrections to past years are required.

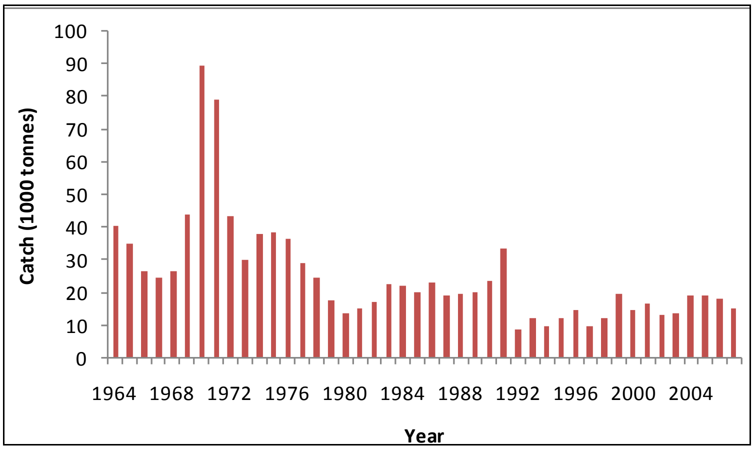

Figure 4.42. Northeast Arctic Greenland halibut; landings 1964-2007.

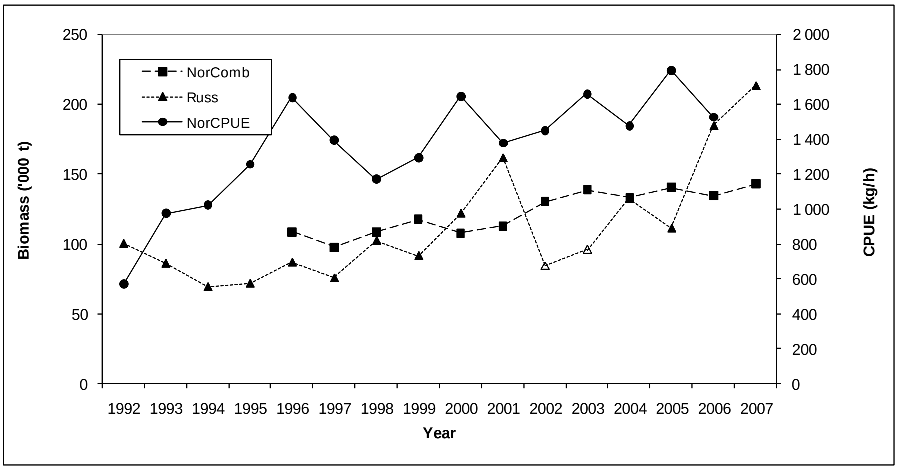

Figure 4.43. Northeast Arctic Greenland halibut; Biomass estimates from three surveys targeting Greenland halibut. NorComb is a combined index of Norwegian surveys covering most of the Barents Sea, Russ is the Russian autumn survey and NorCPUE is a survey covering the central adult area.

4.7.5 Capelin (Mallotus villosus)

The spawning stock (Figure 4.44) of capelin in 2008 is predicted from the acoustic survey in September 2007 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 2008, the probability of having an SSB below 200,000 t is above 15 %. 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 2007 was estimated to be 0.8 mill tonnes. SSB 1st April 2008 is predicted to be at 0.33 mill tonnes. The spawning stock in 2008 will consist of fish from the 2004 and 2005 year classes, but the 2005 year class will dominate. The survey estimate at age 1 of the 2006 year class is below the long-term average, but is the strongest since year 2000. Observations during the international 0-group survey in August-September 2007 indicated that the size of the 2007 year class is above the long term mean.

The estimated annual consumption of capelin by cod has varied between 0.2 and 3.0 million t over the period 1984-2007. Young herring consume capelin larvae, and this predation pressure is thought to be one of the causes for the poor year classes of capelin in the periods 1984-1986, in 1992-1994, and from 2002 onwards.

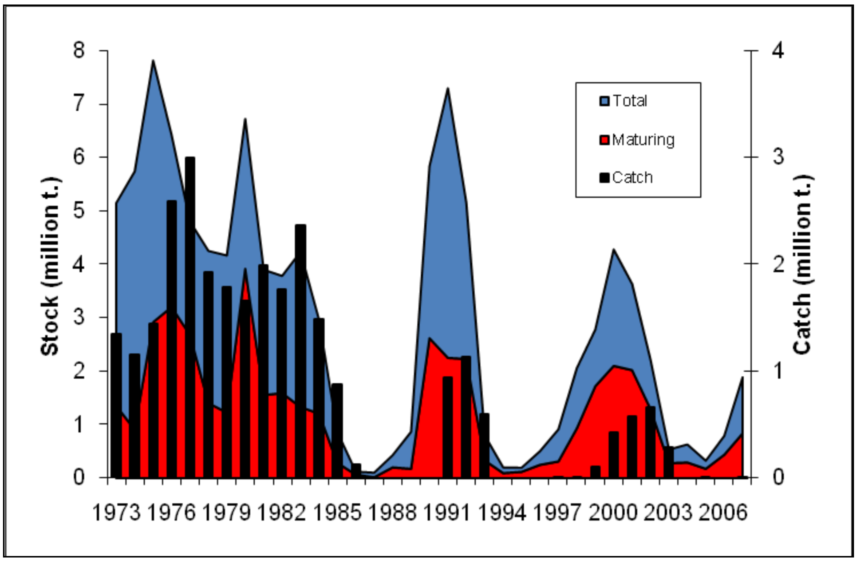

Figure 4.44. Barents Sea capelin. Total stock (blue area) and maturing component (red area) during autumn and total landings (columns), 1973–2007.

4.7.6 Herring (*Clupea harengus*)

Based on the most recent estimates of SSB and fishing mortality, ICES classifies the stock as having full reproductive capacity and being harvested sustainably. The 1998, 1999 and 2002 year classes dominate the current spawning stock which is estimated to 11.9 million t in 2007. The 2004 year class is also estimated to be strong. Parts of this year class were found in the Barents Sea in autumn 2007, but will probably leave the Barents Sea in 2008. Preliminary indications show that the year classes 2005-2007 are below average. Therefore the abundance of herring in the Barents Sea is believed to be at a relatively low level in 2008.

This stock has shown a large dependency on the occasional appearance of very strong year classes (Figure 4.45). In recent years the stock has tended to produce strong year classes more regularly. However, if strong year classes should become more intermittent, the stock is expected to decline.

Norwegian spring-spawning herring is fished along the Norwegian coast and in the Norwegian Sea, but not in the Barents Sea. However, juveniles from this stock play an important part role in the ecosystem in the Barents Sea.

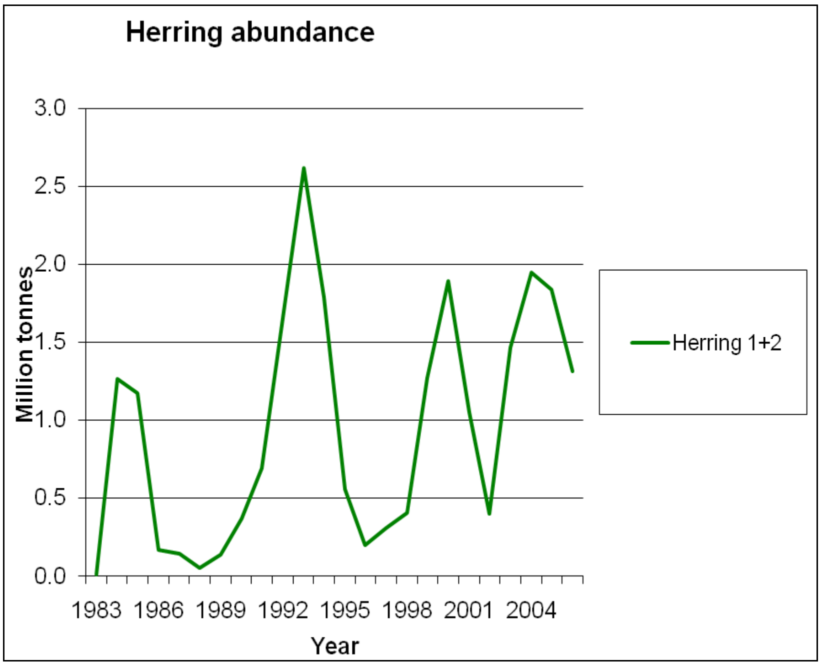

Figure 4.45. Abundance of age 1 and 2 Norwegian Spring-spawning herring (calculated by VPA). This is a good indication of the abundance of young herring in the Barents Sea. Please note that the figure is not updated for 2007.

4.7.7. Polar cod (*Boreogadus saida*)

The polar cod stock is presently at a high level (Figure 4.46). 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 2007, the stock size was measured to about 1.2 million tonnes.

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

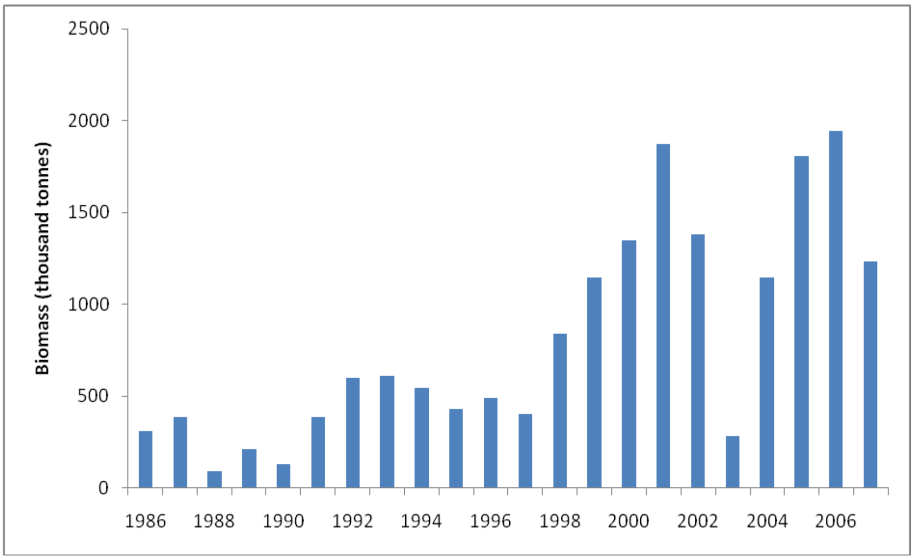

Figure 4.46. Polar cod. Stock size estimates obtained by acoustics, 1986–2007.

4.7.8 Blue whiting (Micromesisius poutassou)

Based on the most recent estimates of fishing mortality and SSB, ICES classifies the stock as having full reproductive capacity, but being harvested unsustainably. SSB increased to a historical high in 2003 but has decreased in 2004-2007. Although the estimates of SSB and fishing mortality are uncertain, the estimate of SSB appears to be well above B_{pa}. The estimated fishing mortality is well above F_{pa}, and close to F_{lim}. Recruitment in the last decade appears to be at a much higher level than earlier, but seems to be decreasing in the last couple of years. Total landings in 2006 were 2.0 mill. tonnes, which is about the same level as in 2005. Recent large landings are supported by the current high recruitments, and are much higher than in earlier years. Blue whiting is not fished in the Barents Sea.

The high abundance of blue whiting in the Barents Sea (Figure 4.47) 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 2004-2007. In autumn 2007, the acoustic abundance of blue whiting was estimated to 0.7 million tonnes, which is about the same level as in 2006. However, 1-group blue whiting was hardly found in the Barents Sea in 2007. Thus, the abundance of blue whiting is expected to decline in 2008 unless there is recruitment from the 2007 year class.

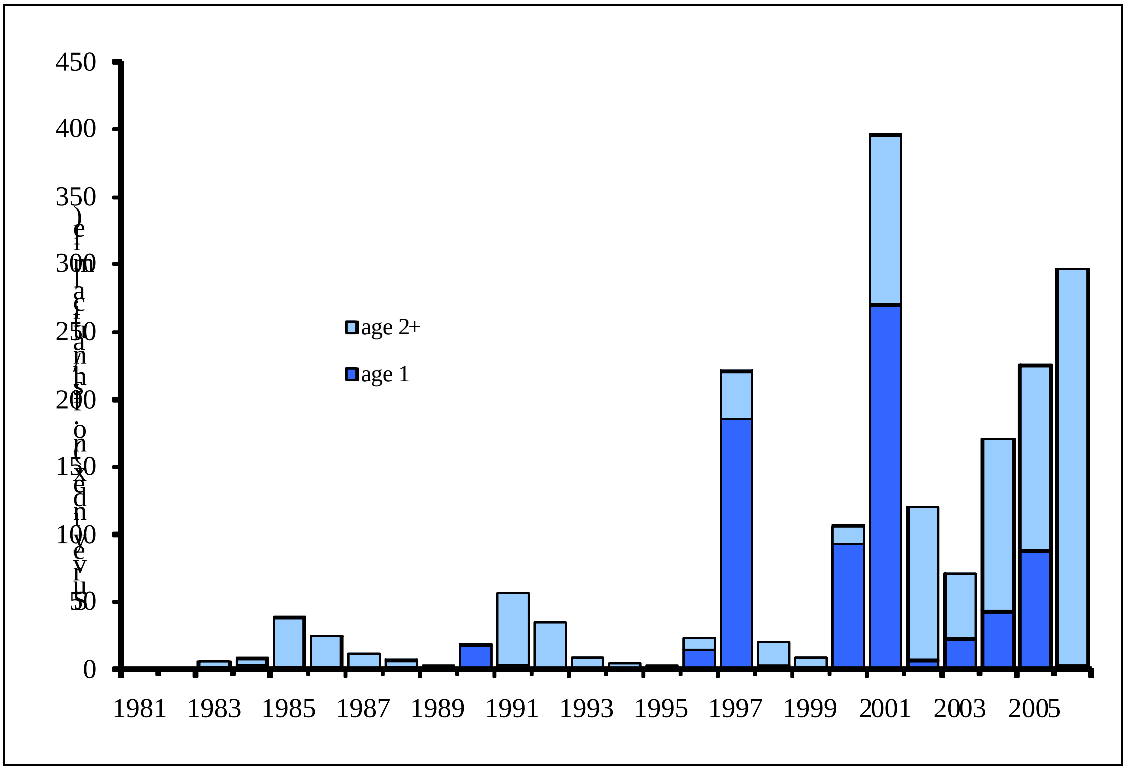

Figure 4.47. Blue Whiting. Abundance (catch in numbers per nautical mile) of blue whiting in the Barents Sea winter survey 1981-2006. Please note that the figure is not updated for 2007.

4.7.9 Saithe (Pollachius virens)

Based on the most recent estimates of SSB, ICES classifies the stock as having full reproductive capacity. Based on the most recent estimates of fishing mortality, ICES classifies the stock to be harvested sustainable. Fishing mortality is stable and has since 1996 been below F_{pa}. The SSB (Figure 4.48) has since 1994 been well above B_{pa}. After a long period of low stock size, the stock recovered during the 1990s with the recruitment of several above-average year classes. The current estimated fishing mortality (0.20) is just above the lowest fishing mortality that would lead to high long-term yields ($F_{0.1}$ =0.14). ICES evaluated a Harvest Control Rule (HCR) for NEA saithe in 2007 and concluded that it was consistent with the precautionary approach. Norwegian authorities implemented the HCR autumn 2007 and applied it when setting TAC for 2008. This rule has the objectives of maintaining high long-term yield, year-to-year stability and full utilization of all available information on stock dynamics. It aims to maintain target F at F_{pa} = 0.35 and to keep the between year TAC change to within +/- 15%, unless SSB falls below B_{pa} when the management targets should change. The highest long-term yield was obtained for an exploitation level of 0.32, i.e. a little below the target F used in the HCR (F_{pa}), and ICES recommended using a lower value in the HCR. However, Norwegian authorities implemented the management strategy with a target F at F_{pa} = 0.35. This implies a TAC of 225 000 t in 2009 if a lower exploitation level still not is used.

In the Norwegian fishery, which at present accounts for more than 90 % of the landings, various gears are used, while other nations mainly use bottom trawl. On average over the last ten years about 40 % of the Norwegian catch originates from bottom trawl, 25 % from purse seine, 20 % from gillnet and 15 % from other conventional gears (long line, Danish seine and hand line). The gillnet fishery is most intense during winter, purse seine in the summer months while the trawl fishery takes place more evenly all year around.

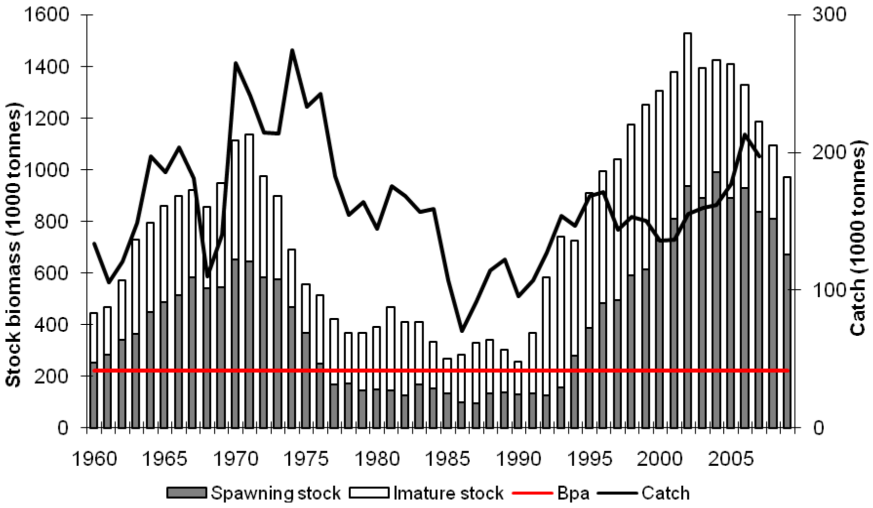

Figure 4.48. Northeast Arctic saithe, development of spawning stock biomass (filled columns), total stock biomass (age 3 and older, filled and open columns) and landings (black line).

4.7.10 Snake pipefish (*Entelurus aequoreus*)

Snake pipefish was first registered in the Barents Sea ecosystem survey in 2005 following an expansion of the species range from the North Sea and northward through the Norwegian Sea. In 2006, the intrusion expanded north to 80˚N and east to 35˚E with scattered observations further east. In 2007 the distribution area remained largely the same as in 2006.

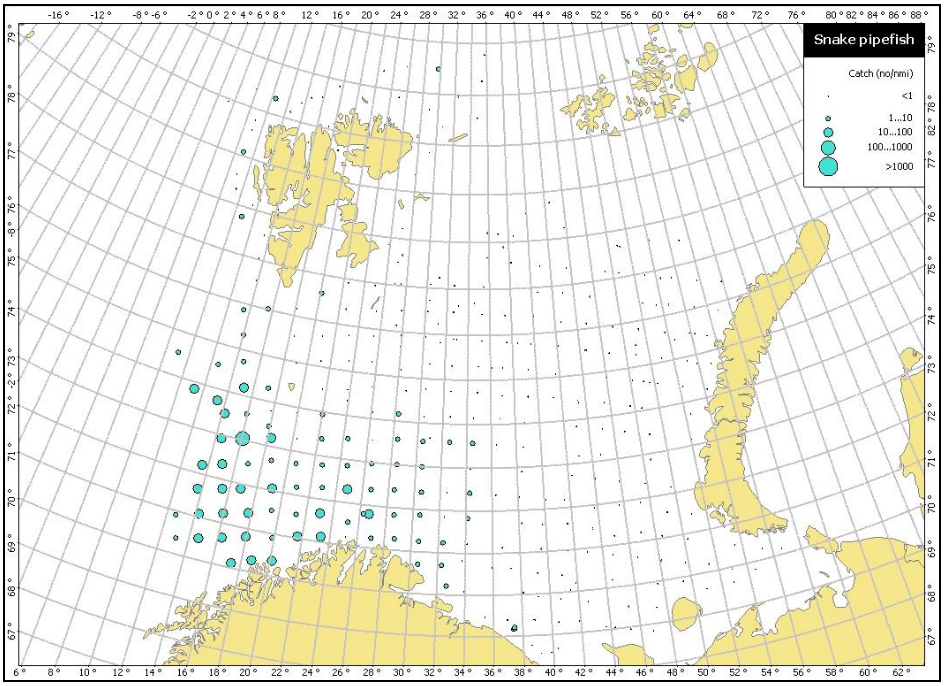

Figure 4.49. Distribution of snake pipefish (Entelurus aequoreus), from ecosystem survey in August-September 2007.

4.8 Marine mammals

By M. Skern-Mauritzen (IMR), V. B. Zabavnikov (PINRO), S. V. Ziryanov (PINRO) and N. Øien (PINRO)

4.8.1 Current state

Information on the current situation of marine mammals in the Barents Sea is obtained from counts for abundance estimation, and from data on distribution from dedicated observers on board research vessels during the ecosystem cruise in August – September and incidental observations from e.g. coastguard and other research vessels throughout the year. The aims of these investigations are to study the ecological processes underlying marine mammal distributions, such as prey selection, prey distribution and habitat use. As marine mammals are long-lived species, short-term fluctuations within the Barents Sea system are more likely to influence the distribution of these top predators and their interactions with prey species, rather than affecting their abundances.

It is important to note that the discussion below is based on the total number of observations received, and these are not effort corrected. Due to higher observation effort on Norwegian vessels (2 dedicated marine mammal observers) is higher than on the Russian vessels (one observer, recording both seabirds and marine mammals) during the ecosystem cruise, the distribution of observations is biased towards the western areas.

In 2007, observations from 15 marine mammal species were recorded by observers during the ecosystem cruises and reported as incidental observations from a variety of vessels. The most abundant cetacean in terms of individuals was the white-beaked dolphin, which was observed over large parts of the Barents Sea (4.50), with aggregations along the shelf edge and around Bear Island, in the south-east and in the north. Compared to last year, more white-beaks were observed in the northern areas, which may be a response to an increasing capelin abundance. In contrast to 2006, where no observations of it's sibling species, the white-sided dolphin, recorded, and no observations of the common or striped dolphins were recorded. White-sided dolphins are more oceanic than the white-beaks, and common and striped dolphins are boreal species occasionally occurring in the Barents Sea. Being a coastal species, harbor porpoises are not well covered by the cruises in the Barents Sea. However, the few observations recorded of harbour porpoises were within it's traditional range (Figure 4.50).

Of the baleen whales, minke, humpback and fin whales were most numerous, and their distributions are shown in Figure 4.51. Minke whales were observed in most parts of the Barents Sea, with aggregations along the shelf edge, around Bear Island, west of Svalbard and in northern areas. Fin whales have a more restricted distribution, but are still continuing the recent trend of occupying central and northern Barents Sea. Nevertheless, the densities are highest in the traditional fin whale area along the shelf edge. Humpback whales were as in previous years observed in dense aggregations within their core areas, along the shelf edge, and on the banks north and east of Bear Island. Humpback whales have the most conservative distributions of the baleen whales.

Blue, sei and bowhead whales are rarer and occasionally observed in the Barents Sea. Three observations of blue whales were recorded west and north of Svalbard, two observations of sei whales were recorded south of bear Island and north of Svalbard, while no observations were recorded of the bowhead whale.

Also the harp seals are occasionally observed in the Barents Sea, and that is not because they are rare. This numerous seal species is associated with sea ice in summer and autumn, and is thus outside the survey areas for most vessels. In 2007, harp seals were observed along the sea ice edge in north in September, and on the Goos bank in southern Barents Sea in October. Countings of harp seal pups in the White Sea in 2005 suggested either a reduction in pup production, and thus in the seal abundance, or a redistribution of whelping seals. In spring 2008 new counts were performed in the White Sea, and additional reconnaissance flights in the south eastern Barents Sea covered the Pechora Sea, areas around Kolguev Island and towards Novaya Zemlya. No abundance estimate is available yet from this count, but numbers of pups are similar to that observed in 2005. Furthermore, no whelping patches were observed outside the White Sea, suggesting that the reduced number of pups reflects fewer seals rather than a redistribution of seals. The causes of a possible decline in this seal population are unknown.

Both minke whales and harp seals are harvested. The total catch of minke whales in the North Atlantic in 2007, 597 individuals, were at the same level as in previous years, and well below the quota set at 1052 whales (Figure 4.52). Also for harp seals in the East Ice the total numbers of seals taken, 11 629 individuals, were well below the quota of 78 200. Furthermore, the number of seals taken was reduced relative to previous years (Figure 4.53)

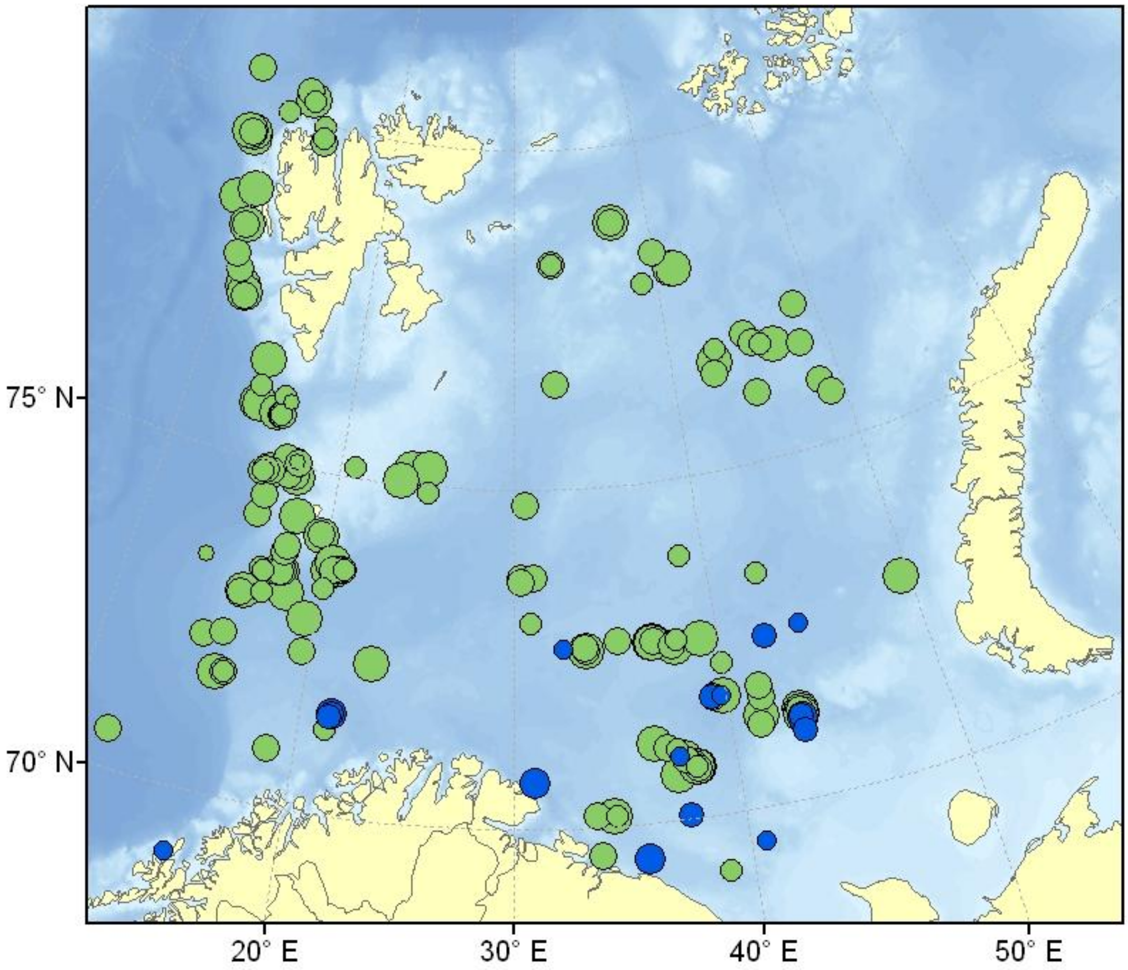

Figure 4.50. Distribution of white-beaked dolphins (green dots) and harbor porpoises (blue dots) as observed in 2007

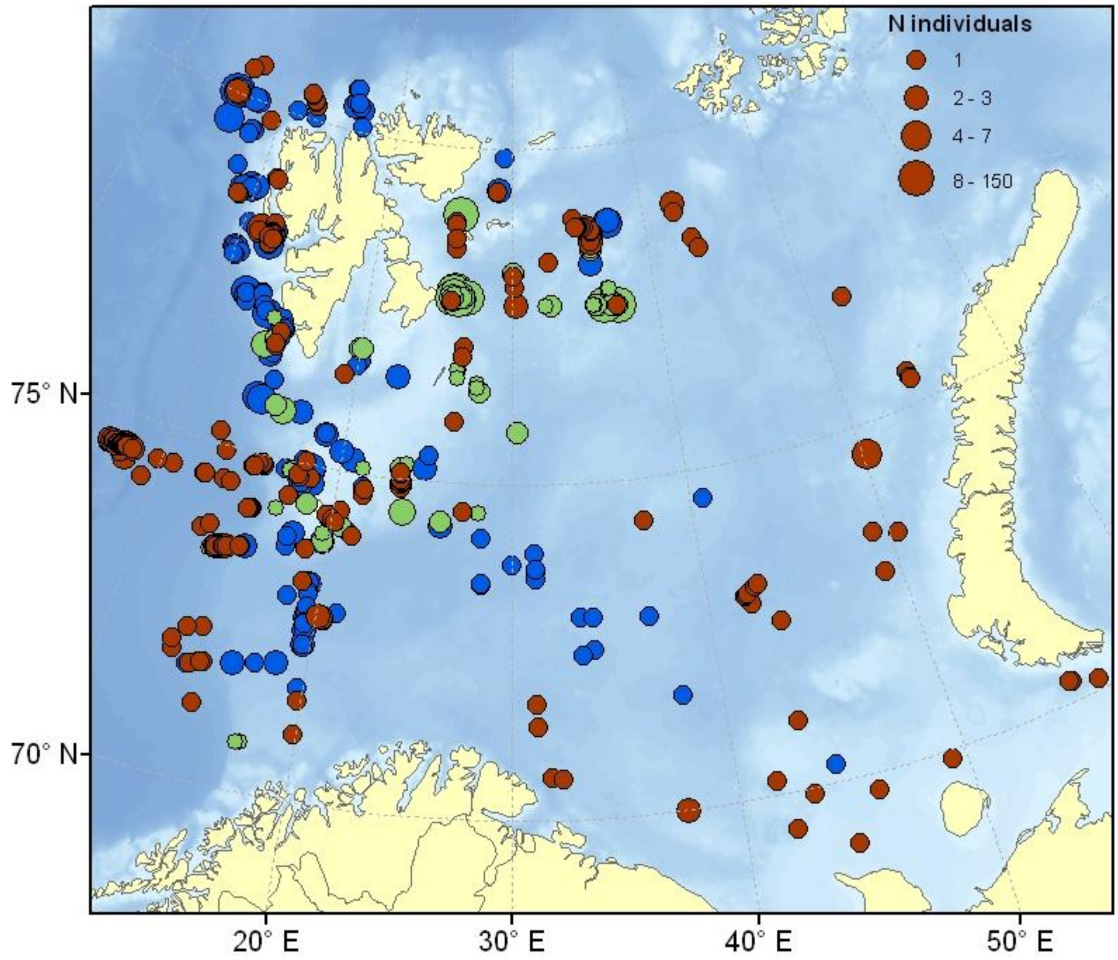

Figure 4.51. Distribution of minke (red dots), humpback (green dots) and fin whales (blue dots) as observed in 2007. Dot sizes reflect number of individuals observed.

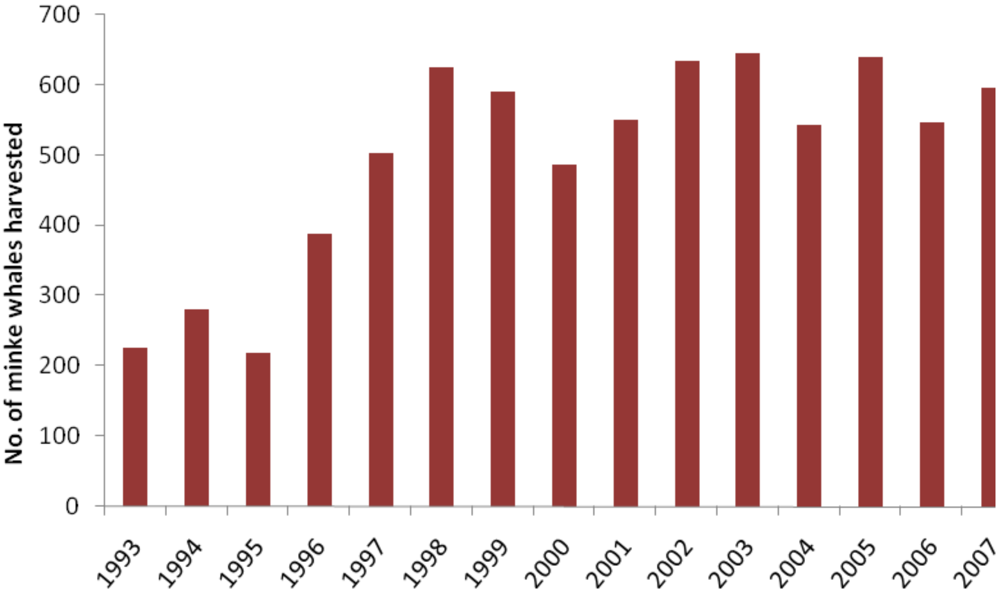

Figure 4.52. Total Norwegian catches of minke whales per year.

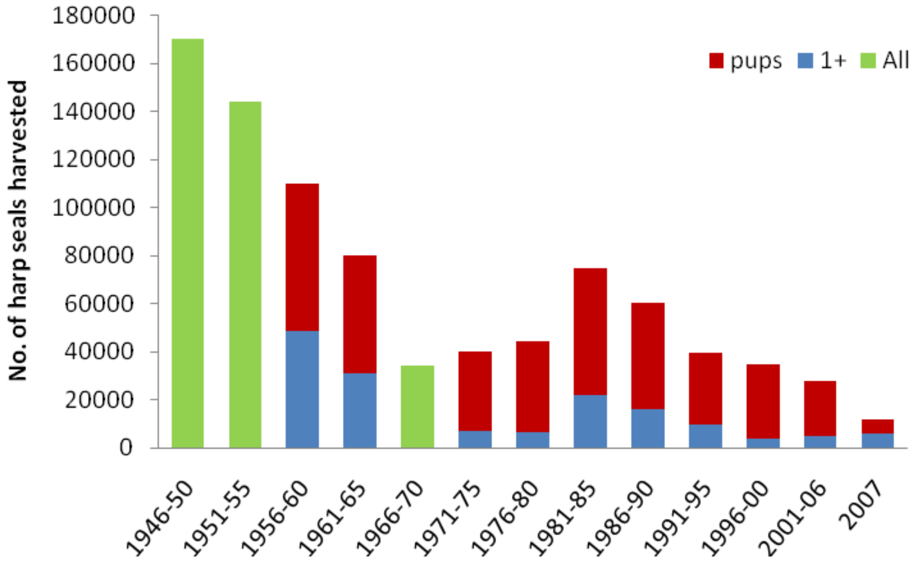

Figure 4.53. Mean total catches in 5-year periods of harp seal pups (red) and older seals (1+ years old, blue) taken in the Barents Sea/White Sea. In some of the earlier years the age structure of catches is not known (green bars).

4.8.2 Expected situation

The baleen whales in the Barents Sea have in the last years aggregated at the rim of the distributions of pelagic fish in northern arctic waters, implying that competition between pelagic fish and whales for zooplankton determine the spatial distribution of the whales (see section 2.5.5 and Figure 2.43). The capelin abundance is expected a continued increase in 2008. Thus, we are now in a unique situation where we can observe how top-predators, such as baleen whales, respond to the return of this key species. Several responses to the increasing capelin abundance may be expected. When densities increase, the competition for zooplankton in northern areas will intensify, this may result in more whales foraging on the abundant pelagic fish stocks in the southern Barents Sea. Alternatively, the whales may switch from zooplankton to capelin when capelin densities become sufficiently high. Baleen whales may very well forage on capelin, but are dependent on high capelin densities for efficient foraging (Piatt and Methven 1992).

Fin whales are normally associated with the deeper Norwegian Sea and the shelf edge, but have the last years been observed also in central parts of the Barents Sea. This range expansion may relate to the situation in the Norwegian Sea, which is currently recognised by high densities of pelagic fish and low densities of zooplankton. As these conditions are expected to prevail also for 2008, we expect that fin whales will occur in the Barents Sea also in 2008.

4.9 Some issues on long-term projections

By K. Drinkwater (IMR), B. Bogstad (IMR), A.A. Filin (PINRO) and L. L. Jørgensen (IMR)

4.9.1 Projections of future climate change

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) undertook an evaluation of the evidence for and impacts of anthropogenic change worldwide where they concluded that human-induced climate change was occurring (IPCC, 2007). As part of the IPCC process, the results from several Ocean-Atmosphere Global Circulation Models were presented. The performances of 20 models for several Arctic regions including the Barents Sea were evaluated by Overland and Wang (2007). Their assessment was based on model's ability to simulated observed seasonal changes in ice concentrations for the period 1979-1999. For the Barents a limit of within 30% was used to determine acceptable models and those exceeding 30% were considered unacceptable. The reasoning was that the models should be able to hindcast the present day conditions if they are to do a good job on future projections. Most of the models had too much ice in the Barents as only 7 models met the acceptable criteria. By 2050 using A1B scenario, 5 of these 7 models indicate a 40% or more loss of sea ice in the Barents Sea. The annual mean temperature in the Barents Sea at the end of the 21st century under the A1B scenarios based on the ensemble mean from all of the IPCC GMCs shows maximum warming of around 7°C but this is felt to be too high due to an overestimate of the albedo feedback caused by the removal of the present-day simulations' excessive sea-ice cover (IPCC, 2007).

The Bergen Climate Model (BCM) was not one of the 7 models that performed well in the IPCC evaluation but early runs of that model had produced more realistic ice coverage. Using the earlier version of the BCM, Furevik et al. (2002) developed future climate scenarios for the Barents Sea. By 2080, they suggested surface ocean temperatures will warm 1° to 2°C (Figure 4.54), winter sea ice will almost disappear, Atlantic waters will spread farther eastward and northward, there will be more continental runoff but it will be partially compensated by inflow of high salinity Atlantic water, and the surface mixed-layer depth will increase due to stronger winds. Recently, as part of the BALANCE (Global Change Vulnerabilities in the Barents Region: Linking Arctic Natural Resources, Climate Change and Economies) project, climate scenarios were obtained from the regional climate model REMO of the Max Planck Institute for Meteorology in Hamburg, Germany and forced by a global climate model driven by a B2 scenario (Lange et al., 2008). This model was used to drive a regional hydrological model, which suggested a 25% increase in freshwater runoff, proportionately larger than the projected precipitation increase (Dankers and Middelkoop, 2008). The snow season was projected to be 30-50 days shorter with the peak spring discharge occurring about 2-3 weeks earlier than in the present day but remaining dominated by snowmelt. Using a regional hydrodynamical ocean model forced by the REMO, Ellingsen et al. (2008) found between 1995 and 2059 that the fraction of water in the Barents Sea with temperatures greater than 1°C increased by 25% (the same magnitude as the present seasonal change) but with high interannual and multi-decadal variability. This temperature rise is largely due to increases in the temperatures of the inflow Atlantic water although there is projected to be no significant change in mean transports of this water. They also noted that sea-ice coverage will decrease with the largest decline during the summer resulting in virtually ice free conditions at this time of the year by 2059. In winter the ice exhibits high variability. Huse and Ellingsen (2008), also as part of BALANCE, examined changes in the position of the Polar Front that separates the cold Arctic and warm Atlantic waters. The frontal position was projected not to change much in the western Barents where it is tied to topographic features but in the eastern Barents the front will move farther north and east (Figure 4.55).

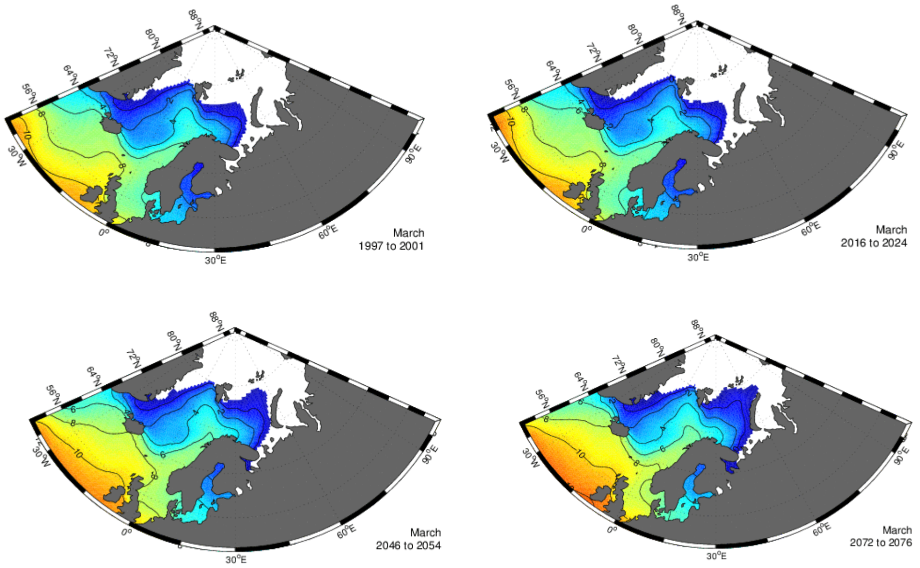

Figure 4.54. Historical and forecast sea surface temperatures and sea ice during March based on the Bergen Climate Model (taken from Furevik et al. 2002).

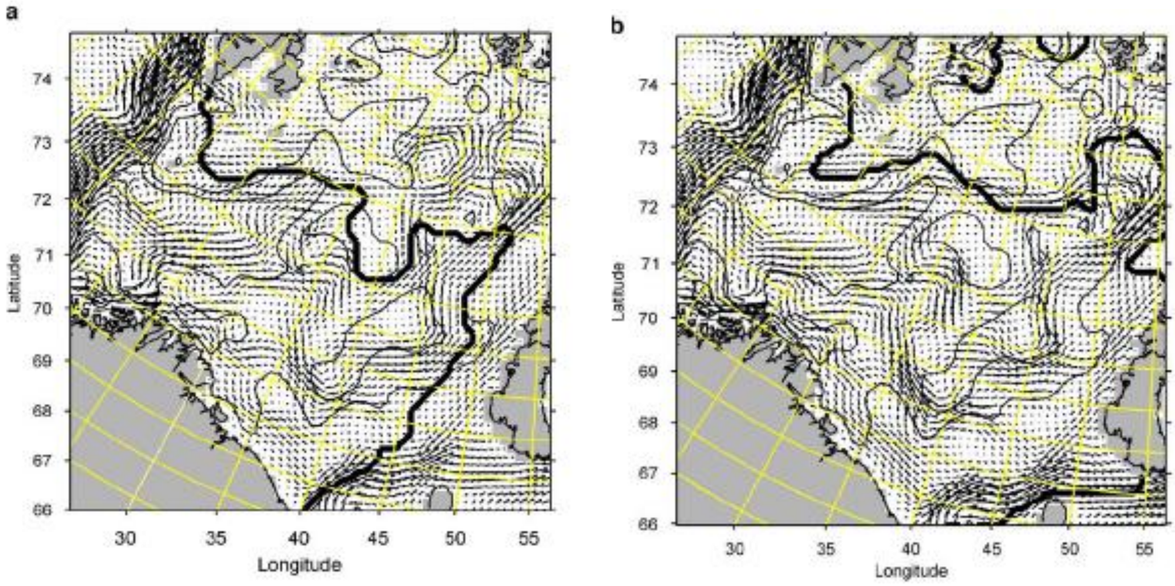

Figure 4.55. The modeled currents and the position of the Polar Front (bold line) for the Barents Sea during (a) 2000 and (b) 2047 (taken from Huse and Ellingsen, 2008)

4.9.2 Projections of the ecosystem response to future climate change

Ellingsen et al. (2008) used a coupled biological-physical model to examine possible changes in the plankton community. Their model indicates a slight (8%) increase in the mean level of phytoplankton production between 1995 and 2059 due principally to increases in the northern Barents. This is due to a combination of higher light levels in areas of decreased ice extent and higher nutrient levels in the Atlantic waters where they extended northward and eastward.

This compares to the 30% increase suggested by Slagstad and Wassmann (1996) between heavy and light ice years. Ellingsen et al. (2008) also predicted that the Atlantic zooplankton production, primarily *Calanus finmarchicus*, would increase by about 20% and spread farther eastward while the Arctic zooplankton biomass would decrease significantly (by 50%) resulting in an overall decrease in zooplankton production in the Barents Sea. The increased Atlantic zooplankton is believed due to both higher transport into the Barents through inflow of warm Atlantic water (Stenevik and Sundby, 2007) and to faster turnover rates due to the higher temperatures, as suggested by Tittensor et al. (2003) for the Labrador Sea.

The higher phytoplankton and zooplankton production is expected to result in increased fish production. For example, model studies show that higher primary production tends to lead to an increase in cod recruitment in the Barents Sea (Svendsen et al., 2007). Higher temperatures should lead to improved growth rates together with the expected increased recruitment will lead to increased fish yields (Drinkwater, 2005; Stenevik and Sundby, 2007). The higher overall production is expected to produce increased catches of cod, haddock and other species (ACIA, 2005). More fish will spawn farther north (Sundby and Nakken, 2008; Drinkwater 2005), and new spawning sites will likely be established. Possible impacts on the capelin population were explored by Huse and Ellingsen (2008). The movement of the Polar Front farther north and east will result in a shift in the adult capelin distribution towards the northeastern Barents Sea, consistent with distributional changes under observed cold and warm years by (Gjøsæter, 1998). Capelin is also predicted to spawn earlier and to shift their spawning sites eastwards from their present position off northern Norway and establish new spawning locations along Novaya Zemlya. Herring, blue whiting and possibly Atlantic mackerel will spread farther eastward resulting in new species interactions and potentially change the structure and function of the Barents Sea ecosystem. Salmon abundance likely will increase in Russian waters as previously observed under warmer conditions (Lajus et al. 2005) and also extend to northern Svalbard. The distribution shifts of fish will result in a higher proportion of the fish (such as cod and haddock) into Russian waters although because of expected increases in total production, the total number of fish in both the Norwegian and Russian economic zones should increase (Stenevik and Sundby, 2007). Under the projected warming in the Barents Sea, Atlantic Water species of fish and benthos are expected to extend farther east and north (Drinkwater, 2005; ACIA, 2005; Stenevik and Sundby, 2007), although this will depend to a large degree upon the future fishing intensity. Indeed, examining the effect of different management regimes on Norwegian cod fisheries in conjunction with climate change, Eide (2008) concluded that these management schemes will play a more significant role than climate change on the economic performance of the fishing industry in the Barents Sea.

Bioclimate envelope models can be used to predict possible impacts to future climate change. Bioclimate envelopes are a set of physical and biological conditions that are suitable to a given species and are generally identified from present associations. Shifts in species distributions under climate change can thus be predicted by evaluating changes in the bioclimate envelope. Cheung et al. (2008) determined the responses of several species around the world to climate change after 30 years using bioclimate envelope models that included sea temperatures, bathymetry, habitat and distance from sea ice. Two of the species they examined were Atlantic cod and polar cod. For the former, they found that for the Barents Sea there would be an increase in overall abundance with a shift in distribution eastward and northward with a large increase in the Russian zone (Figure 4.56). The increased abundance is similar to the projections made by Drinkwater (2005) based upon temperature-recruitment relationships and the distributional shifts are consistent with Stenevik and Sundby (2007).

For the polar cod, the population would all but disappear from the Barents Sea after approximately 30 years.

Vikebø et al. (2007) examined the potential impact of a reduction in the thermohaline circulation (THC) in the North Atlantic on the larval drift of the North-east Arctic cod. This circulation pattern brings warm water north which cools, sinks and returns as a deep water current. Using a Regional Ocean Modelling Systems (ROMS), they imposed a 3 times present river discharge to the Nordic Seas and the Arctic Ocean greatly reduces the strength of the THC by 35%. This is near the projected reduction of around 25% in the THC predicted by the end of the 21st century in the IPCC (2007) report. Vikebø et al (2007) found that this reduction results in a south and westward drift of cod year classes from the Barents onto the Norwegian and Svalbard shelves, a reduction in the numbers of pelagic juveniles that survive, and an increase in the proportion of larvae and juveniles advected along West Svalbard and possibly into the Arctic Ocean. These latter would not be expected to survive, however.

It must be cautioned that the atmospheric and ocean climate scenarios as well as their impacts remain highly uncertain. Better regional models of the Barents through downscaling from the GCMs are required. A recent downscaling exercise in the North Sea using the BCM atmospheric model by Ådlandsvik (2008) pointed out the need to undertake the downscaling using many models and perhaps take an ensemble mean and not be based upon just one GCM. Also, climate change is just one of the global change issues that the marine environment is subjected to and other issues such as fishing or acidification will also play roles and must be taken into accounted into projections of future.

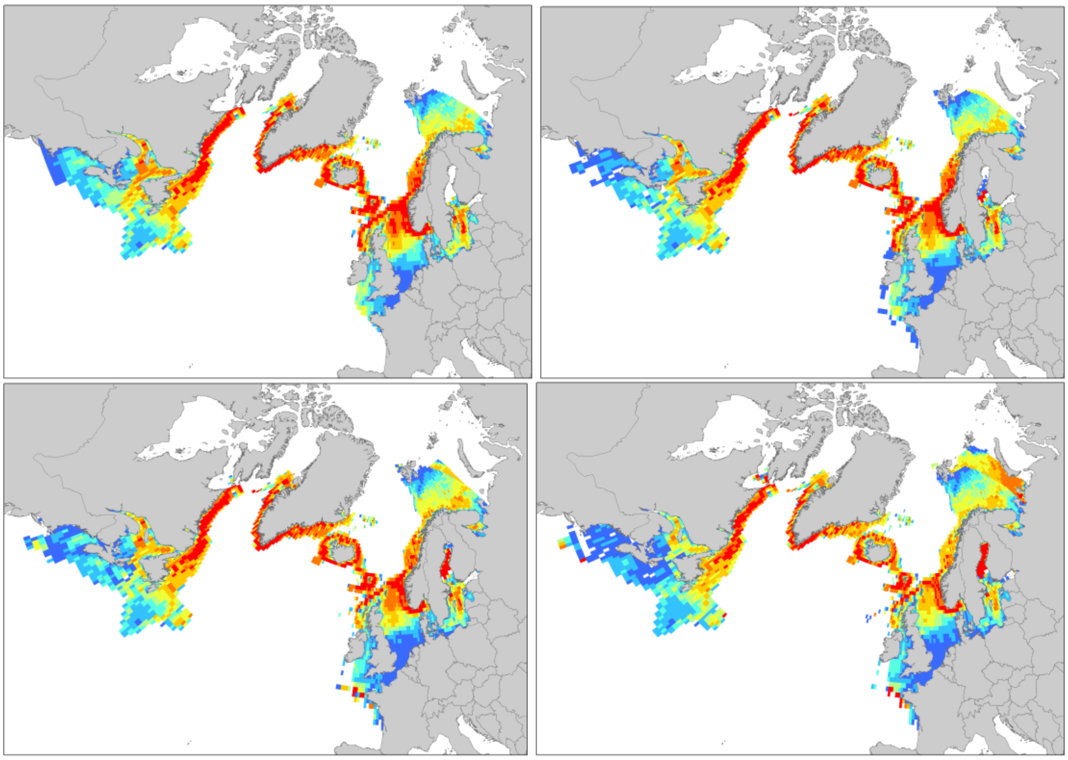

Figure 4.56. Simulated changes 60 year ahead in the distribution of Atlantic cod under ocean warming. Upper left panel is year 2000, upper right panel is year 2020, bottom left panel is year 2040 and bottom right panel is year 2060. (Updated simulations of Chueng et al, 2008, conducted in 2008 by the same group, printed with permission)

The results of long-term simulations by STOCOBAR model (more detailed about this model see subchapter 5.2.3) show that a rising of temperature in the Barents Sea by 1-4C° will lead to acceleration of cod growth and maturation rates. This will positively affect the general production of the cod stock. On the other side cannibalism of cod will also increase in response to expected warming in the Barents Sea, which will have a negative effect for cod recruitment and total abundance.

The summarized consequences of temperature increase in the Barents Sea for the cod stock and catches are presented in Figure 4.57. The harvest control rule for cod in the simulations correspondents to the management strategy which is based at the precautionary approach. The cod yield for the all temperature scenarios were calculated using existing values of the biological references points for the cod stock.

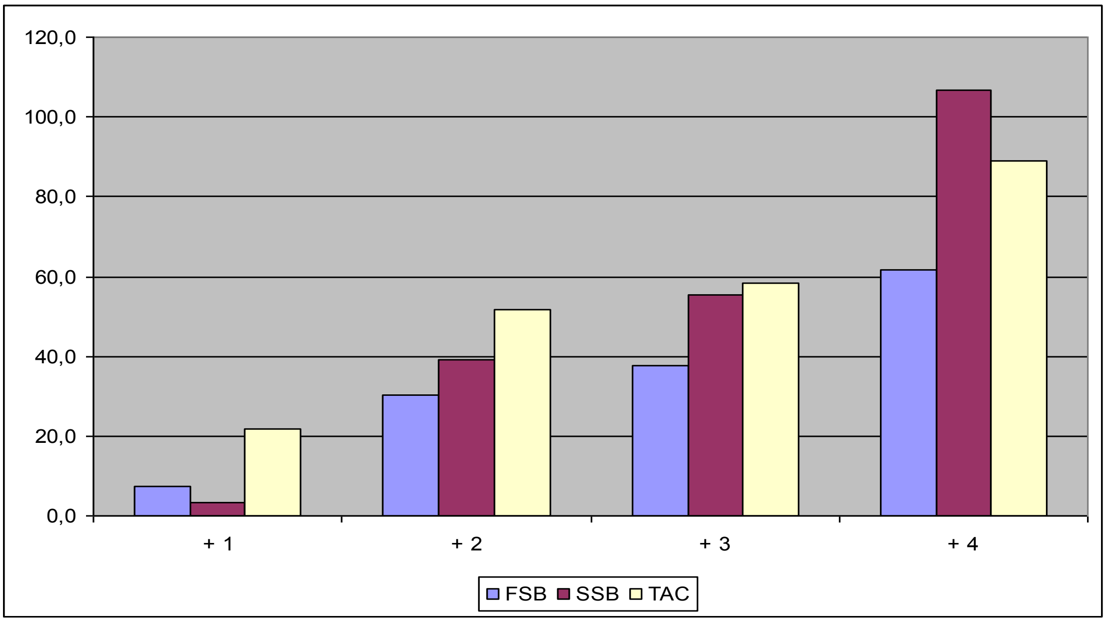

Figure 4.57. Relative changes (% to simulated values under the current temperature regime) of cod stock biomass and catches at temperature increase in the Barents Sea by 1-4 C° according to the STOCOBAR simulations. FSB – fishable stock biomass, SSB – spawning stock bimass, TAC – total allowable catch.

4.9.3 Benthos and climatic change

Climate change resulting in altered composition of Arctic versus Atlantic water masses will influence the transition zone between the Arctic Region and the Eastern North Atlantic Boreal Region, with changes in the distribution of organisms (Blacker 1957). Conspicuous echinoderms and bivalves with Atlantic affinities, which have established themselves with a self-sustainable population in areas previously defined as the Arctic region is an indicator of a long-term increase in temperature in that area. In an increasing temperature scenario, southern species will become more frequent than now and the species composition of the benthos will change. A shift in the benthic communities towards boreal species at the expense of Arctic species is expected. Such changes will affect benthic production (i.e. food for demersal fishes and other vertebrates) and may therefore have severe management implications.

Future fluctuations in zoobenthic communities will be related to the temperature tolerance of the animals and the future temperature of the seawater. Whereas a majority of the boreal forms have planktonic larvae that need a fairly long period to develop into maturity, arctic species do not (Torson, 1950). Consequently, boreal species should be quick to spread with warm currents in periods with warming, whereas the more stenothermal arctic species will perish quickly. During periods of cooling, the arctic species, with their absence of pelagic stages, should slowly follow the receding warm waters. Boreal species that can survive in near-freezing water could continue to live in the cooler areas.

In a climate change scenario, with increasing temperatures, thermophilic species will become more frequent than now. This will essentially force changes to occur in zoobenthos community structure and, to a lesser extent, on its functional characteristics, especially in coastal areas.

4.9.4 Model analysis consequences of changes in marine mammals mbundance for fish stock dynamics in the Barents Sea

Results from MULTSPEC simulations (Bogstad *et al.* 1997) showed that the herring stock is much more sensitive to changes in the minke whale stock than changes in the harp seal stock. Because in the model development in the capelin stock is strongly determined by changes in the herring stock when the minke whale stock increases or decreases the capelin stock increases or decreases. Since herring is less sensitive to changes in the harp seal stock than to changes in the minke whale stock, and since predation on capelin from harp seals is high, an increase or decrease in the harp seal stock leads to a decrease or increase in the capelin stock. The cod stock will increase or decrease when marine mammals stocks decrease or increase. One interesting feature, which reflects the complexity of the system, is that there, would be large gains on average in the cod fishery by removing the seals than by removing the whales, despite the fact that whales eat more cod than seals do in the model runs. The explanation lies in the indirect effect through the herring-capelin-cod dynamics: Removing whales has a large effect on the herring stock, leading to strongly reduced capelin stock and thereby reduced cod stock growth, while removing harp seals would not have the similar indirect effect in model.

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

5 Ecosystem information potential for improvement of advice for sustainable fisheries

By A. A. Filin (PINRO), B. Bogstad (IMR), H. Gjøsæter (IMR), V. A. Ivshin (PINRO),
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5.1 How management strategies may be improved by applying ecosystem information

Ecosystem information ought to play an important role in the design of fishery management strategies. We can use this information to exploit a stock either more efficiently or more carefully, according to the prevailing environmental conditions. A close connection between environmental fluctuations and variation in population parameters of commercial fish in the Barents Sea was suggested already by Helland-Hansen and Nansen (1909) and has been corroborated during recent years. Management of fisheries is always based on decision making under uncertainty. Incorporating data on ocean climate, lower trophic level bio-production as well as species interactions on higher trophic levels in catch recommendations for target species should reduce uncertainty of scientific recommendations for sustainable harvest levels.

The fisheries strategy at first has to ensure a sustainable harvesting. For the achievement of this aim, both the precautionary and ecosystem approaches should be used. According to the precautionary principles, the biological reference points, which are expressed in terms of fishing mortality and spawning stock biomass, should be used in the management procedure. Today, these reference points are constant and independent of the state of the ecosystem. For this reason they are inconsistent to ecosystem approach. If we see a long lasting change in the productivity of the harvesting stocks induced by ecosystem regime change or are able to identify good qualitative relationships between environmental actors and growth or recruitment commercial species, we may imagine that the reference points will be set as a function of the state of the environment. This would allow stocks to be harvested more heavily in more productive periods than in poor periods.

Fishery management in the Barents Sea is conducted through the Joint Russian-Norwegian Fishery Commission, which is a political body at the governmental level, and which acts based on advice from the International Council for Exploration of the Sea (ICES).The existing ICES advice system was designed to provide advice only on a very short-term basis: one year ahead based on recent past. As we now move to provision of longer-term advice there is a need to alter the way we consider the future and to provide advice that is both more robust and more adaptive to change. We need to take into account not only of stochastic variability but also trends and shifts in the environment as we develop scientific advice. Exploitation rates estimated from observations taken over several ecosystem regime changes will not be optimal for any specific set of environmental conditions.

The only way to select the management strategy that best meets the specified objectives is simulation modelling approach. So to move from the constant biological references points for harvesting control to biological references points which will be dependent on ecosystem regime, we need to develop relevant fish-ecosystem coupled models. These models will need a prognosis of the ecosystem state. Where no basis exists for predicting environmental drivers into the future, management strategies should be based on scenario testing.

Simulation should be based on stochastic approach to ensure that the resulting management recommendations are sufficiently robust. Taking into account uncertainties, the probability can be expressed in terms of a risk estimate of undesirable consequences for the stock and harvest implementing a testing strategy. Especially it concerns the probability of declining of stock level below the established threshold level. Alternative future scenarios should be used to evaluate future risks and uncertainties for management. Scientific advice also should be selected from a number of options elaborated in response to expected ecosystem changes.

The current and expected state of the Barents Sea ecosystem and implementation of ecosystem considerations into stock assessments and to the fishery management in the Barents Sea has been considered routinely by the ICES Arctic Fisheries Working Group (AFWG) since 2002. The main aim of this is to include data on environmental and trophic interactions in management advice. Apart from ICES, the joint IMR/PINRO study on the development of an ecosystem approach to the fisheries management in the Barents Sea is conducted at the request of the Norwegian - Russian Fishery Commission. In 2003 the Commission asked IMR and PINRO to evaluate the prospects for long-term yield of commercial species in the Barents Sea taking into account species interactions and the influence from the environment. To meet this request, a joint IMR/PINRO project on evaluation of optimal long-term harvest in the Barents Sea Ecosystem was initiated (Filin and Tjelmeland 2005).

5.2 Methods and tools for implementation of ecosystem information in fisheries management

Availability of necessary ecosystem information is only one of the needed items for implementation of an ecosystem approach to management. Another element that is needed is the development of appropriate methods and instruments to incorporate the ecosystem information into stock assessment and harvest control rules.

Presently we have the following methods and tools for implication of ecosystem information in fisheries management in the Barents Sea, which are used or have potential for application at the AFWG:

1. Qualitative estimations of ecosystem impact on population parameters of commercial species
2. Statistical models
3. Multispecies and fish-ecosystem coupled models
4. Models for simulation of the drift of eggs and larvae of commercial fish species
5. Inclusion of data on cod predation into stock assessment for cod and haddock
6. Inclusion of data on cod predation into estimation of TAC for capelin

5.2.1 Qualitative estimations of ecosystem impact on population parameters for commercial species

The simplest way to look at the future development of the commercial fish stocks, taking into account the ecosystem considerations, is to give qualitatively assignments on different stock parameters from major impact factors. Then an overall effect on the specific stock can be given. The advantage of this approach compared to quantitative methods, is that it can potentially use all available ecosystem information. The deficiency is high subjectivism in estimations.

5.2.2 Statistical models

5.2.2.1 Recruitment of commercial fish

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

Cod

Several statistical models, which use multiple linear regressions, have been developed for recruitment of North East Arctic cod. All models try to predict recruitment at age 3 (at 1 January), as calculated from the VPA, with cannibalism included. This quantity is denoted as R3.

Stiansen et al. (2005) developed a model (JES1) with 2 year prediction possibility:

JES1: R3~ Temp(-3) + Age1(-2) + MatBio(-2)
JES2: R3~ Temp(-3) + Age2(-1) + MatBio(-2)
JES3: R3~ Temp(-3) + Age3(0) + MatBio(-2)

Temp is the Kola yearly temperature (0-200m), Age1 is the winter survey bottom trawl index for cod age 1 (Table A3), and MatBio the maturing biomass of capelin. The number in parenthesis is the time lag in years. Two other similar models (JES2, JES3) can be made by substituting the term Age1(-2) with Age2(-1) and Age3(0), respectively (winter survey bottom trawl index for cod age 2 and age 3, respectively).

Svendsen et al. (2007) used a model (SV) based only on data from the ROMS numerical hydro-dynamical model, with 3 year prognosis possibility:

SV: R3~ Phyto(-3) + Inflow(-3)

where Phyto is the modelled phytoplankton production in the whole Barents Sea, and Inflow is the modelled inflow through the western entrance to the Barents Sea in the autumn. The number in parenthesis is the time lag in years.

The recruitment model (TB) suggested by T. Bulgakova (AFWG 2005 WD14, WD9) is a modification of Ricker's model for stock-recruitment defined by:

TB: R3~ m(-3) exp[-SSB(-3) + N(-3)]

where R3 is the number of age3 recruits for NEA cod, m is an index of population fecundity, SSB is the spawning stock biomass, and N is equal to the numbers of months with positive temperature anomalies (TA) on the Kola Section in the birth year for the year class. The number in parenthesis is the time lag in years. For intervals after 1998, the TA was calculated with relatively linear trend of temperature.

Titov (AFWG 2005 WD16 and WD23) developed models with 1 to 4 year prediction possibility (TITOV1, TITOV2, TITOV3, TITOV4, respectively), based on the oxygen saturation at bottom layers of the Kola section stations 3-7 (OxSat), air temperature at the Murmansk station (Ta), water temperature: 3-7 stations of the Kola section (layer 0-200m) (Tw), ice coverage in the Barents Sea (I), spawning stock biomass (SSB), and the acoustic abundance of cod at age 1 and 2, derived from the joint winter Barents Sea acoustic survey (table A2):

TITOV1: $R3^1 \sim DOxSat^2(t-13) + DOxSat(t-13) + ITa(t-39) + CodA2(t-11) + Tw(t-17)$
TITOV2: $R3^2 \sim DOxSat^2(t-13) - DOxSat(t-13) + ITa(t-39) + CodA1(t-23) + Tw(t-17)$
TITOV3: $R3^3 \sim OxSat^2(t-44) + ITa(t-39) + Cod0(t-28)$
TITOV4: $R3^4 \sim OxSat^2(t-44) + ITa(t-39) + SSB(t-36)$

Where $DOxSat(t-13) \sim Exp(OxSat(t-13)) - OxSat(t-38)$, $ITa(t-39) \sim I(t-39) + Ta(t-44)$. The number in parenthesis is the time lag in months, relative to 1 January at age 3. The ITa index coincides in time with the increase of horizontal gradients of water temperatures in the area of the Polar Front (Titov, 2001).

At the ICES Arctic Fisheries Working Group (AFWG) assessment in 2008 the NEA cod age 3 recruits was calculated by a hybrid model (arithmetical mean) of some of these models was chosen for the short term prediction of age 3 NEA cod, and thereby in the stock prognosis calculations.

Prognoses from existing models are shown in Table 5.1 (from ICES/AFWG 2008). Figure 5.1 show the consistency between the hybrid model, observed data and historical assessment prognosis (ICES/AFWG2008).

Table 5.1. Overview of available prognoses of NEA cod recruitment (million age 3 fish) from different recruitment models together with the 2008 assessment estimates (AFWG 2008). Note that the given month in the third column indicates when the prognoses can be extended for another year.

MODEL	PROGNOSTIC YEARS	PROGNOSES AVAILABLE	2008 PROGNOSES	2009 PROGNOSES	2010 PROGNOSES
Titov1	1 (2 [1])	At assessment	618 *	579	
Titov2	2	At assessment	760	556 *	
Titov3	3	At assessment	817 *	180 *	152 *
Titov4	4	At assessment	826	332	264
TB	3	Before assessment	705	790	624
JES1	2 (3 [2])	November (March [1])	706 *	792 *	722
JES2	1 (2 [2])	November (March [1])	691	637	
JES3	0 (1 [2])	November (March [1])	600		
SV	3	Februar	624	642	
RCT3 Assessment 2008	3	At assessment	607	428	373
Hybrid model			714	509	152
RCT3 Assessment 2007 (Nor-IUU-Run/Rus-IUU-Run)	3	At assessment	535/ 476	461/ 406	

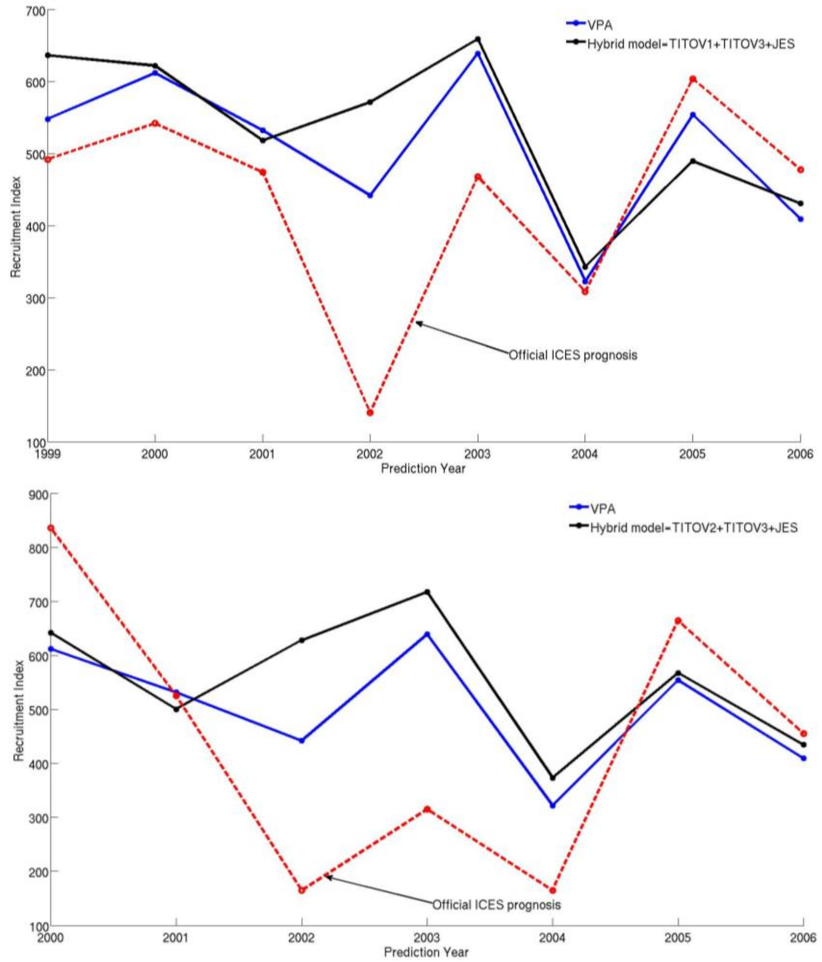

Figure 5.1. Comparison of NEA cod recruitment models. Prognosis for 1-year ahead (upper panel) and 2- years ahead (lower panel).

<u>0-group abundance of Norwegian spring-spawning herring</u>

Multiple linear regression equations for the 0-group herring abundance indices in the Barents Sea were built (Trofimov, Prokhorova, Ivshin, Krysov, 2008). The area index (Ind) and index of absolute abundance (Abund) (corrected for catching efficiency) are used as indices of 0-group herring abundance. The area index represents a sum of two areas: an area occupied by scattered fish concentrations and an area occupied by dense concentrations multiplied by 10.

The following predictors were used: the spawning stock biomass of herring in million tons (SSB), the water density difference between the bottom and surface in the spawning areas in February-March (dD), the indicator of water stratification in the spawning areas in February-March (VStr), the autumn-winter (October-January) North Atlantic Oscillation index (NAO), the total volume fluxes through the sections crossing the North Cape Current (averaged for June-July), Northern (June-July) and Central (June-July) branches of the North Cape Current respectively (NCc_{VI-VII}, $NbNCc_{VI-VII}$, $CbNCc_{VI-VII}$), and the water temperature in the 0-50 m layer in the Kola section in August (T_{0-50}).

The area index of 0-group herring for 1983-1992 was calculated on the basis of maps of young fish distribution. Both the area index of abundance for 1993-2004 and the index of absolute abundance for 1983-2004 were taken from the joint Russian-Norwegian report by results of the ecosystem survey in the Barents Sea in 2005 (Anon., 2005). The indicator of water stratification presents the normalized time of herring larvae ascent from the bottom to the surface, and it was calculated using the model of ascent (Trofimov, Ivshin, Mukhina, 2003).

Figure 5.2 and Figure 5.3 show the consistency of the modelled and observed abundance 0-group herring abundance indices in the Barents Sea.

The regression equations reliability was verified with a jack-knife method (Tukey, 1981), and their probability was 59 to 82% and exceeded the probability of the deviation from the long-term mean (36%) by more than 18% at the same error of ±0,674σ. It verified that these equations could be used for restoration and estimation of the indices of 0-group herring abundance.

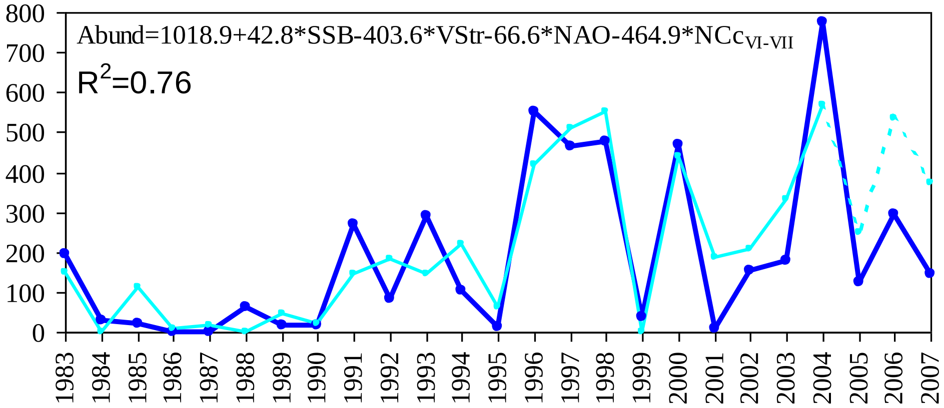

Figure 5.2. The index of absolute abundance for 0-group herring in the Barents Sea: blue line – observed, light blue line – modelled, dashed line – calculation at independent data.

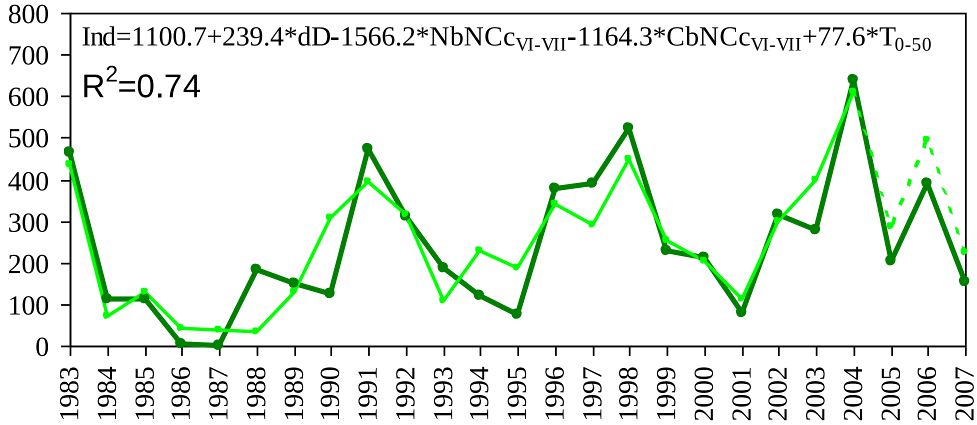

Figure 5.3. The area index of 0-group herring abundance in the Barents Sea: green line – observed, light green line – modeled, dashed line – calculation at independent data.

5.2.2.2 Growth of fish

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

Cod

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

Capelin

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

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

Multiple linear regression equations for the capelin growth rate in the Barents Sea were built in PINRO. The weight increment of capelin aged 1+ (ΔW_{12}) was described by three independent variables (I):

$$\Delta W_{12} = -0,00766 Num + 1/69931 T + 0/00664 Fr - 3,96644 \qquad \text{(I)}$$

$R^2 = 0.73$, $p < 0.00008$, Std. Error Est. = 1.8267, $n = 32$

where *Num* – the capelin abundance at age 1 in the previous year;
T – water temperature in the coastal branch of the Murmansk Current (the Kola Section, Stations 1-3, 0-50 m layer) in the fourth quarter of the previous year;
Fr-index of the frontal zone extent in September of the previous year.

The calculation of frontal thermal zone extent was made as follows: In the area, between 73-78ºN and 15-43ºE, the fields of water temperature horizontal gradients were calculated on a 10’ (latitude) x 30’ (longitude) grid. The index of frontal zone extent represents the total number of grid points net in which the temperature horizontal gradient exceeded the critical value of 0.04ºC/km.

Figure 5.4 shows the consistency of the modelled and observed capelin weight increments at age 1+ in the Barents Sea.

The weight increments of capelin aged 2+ (ΔW_{23}) were also described by three independent variables (2):

$$\Delta W_{23} = 0.41802NAO + 1.44841T + 0.01018Fr - 2.87648, \qquad (2)$$

$$R^2 = 0.60,\ p < 0.00489, \qquad Std.\ Error\ Est. = 2.7186,\ n = 33$$

where *NAO* – the index of the North Atlantic Oscillation in February of the previous year;
T – water temperature in the coastal branch of the Murman Current (the Kola Section, Stations 1-3, 0-50 m layer) in December of the previous year;
Fr- index of frontal zone extent in September of the previous year.

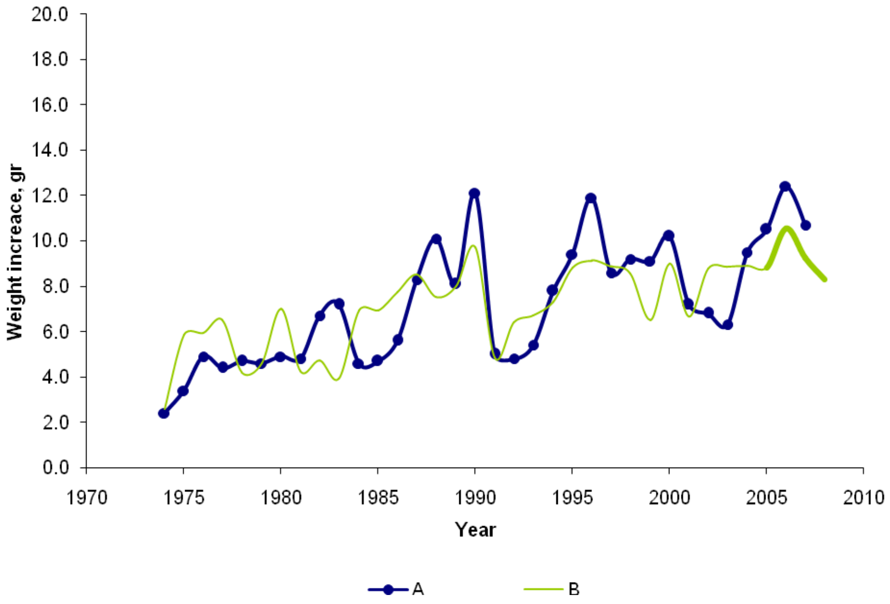

Figure 5.4. Year-to-year variability of capelin increments at age 1+ (A) and the results of statistical modelling (B).

Figure 5.5 shows the consistency of the modelled and observed capelin weight increments at age 2+ in the Barents Sea.

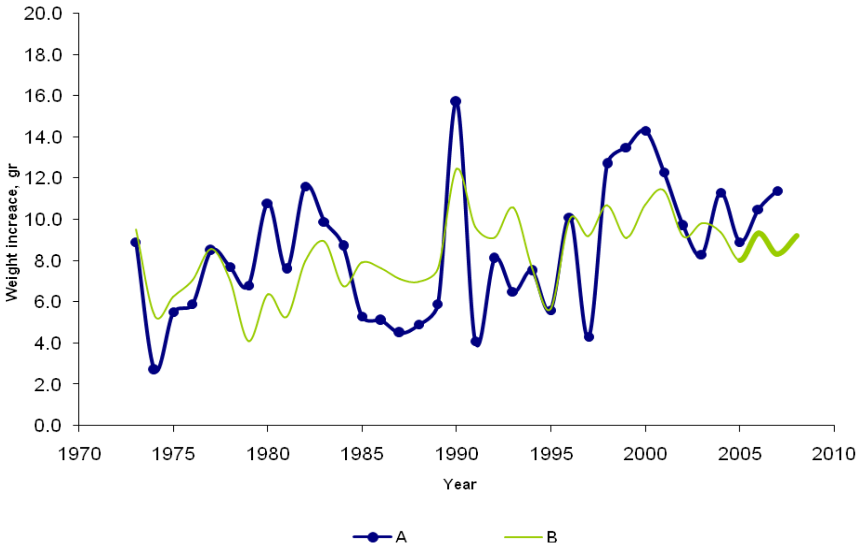

Figure 5.5. Year-to-year variability in the weight increments of capelin aged 2+ (A) and the results of statistic modelling (B).

To describe the weight for capelin aged 3+ (ΔW_{34}) equation (3) was derived:

$$\Delta W_{34} = 1.54086NAO + 1.46834T + 0.00070Krill - 8.73856, \qquad (3)$$

$$R^2 = 0.62, p < 0.00336, \qquad Std.\ Error\ Est. = 3.5756, n = 32$$

where *NAO* – the index of the North Atlantic Oscillation in May of the previous year;
T – water temperature in the central branch of the North Cape Current (the Kola Section, - Stations 8-10, 0-50 m layer) in April of the previous year;
Krill – abundance index of euphausiids from the winter macro-plankton survey in coastal, central and eastern parts of the Barents Sea.

Figure 5.6 shows the consistency of the modelled and observed capelin weight increments at age 3+ in the Barents Sea.

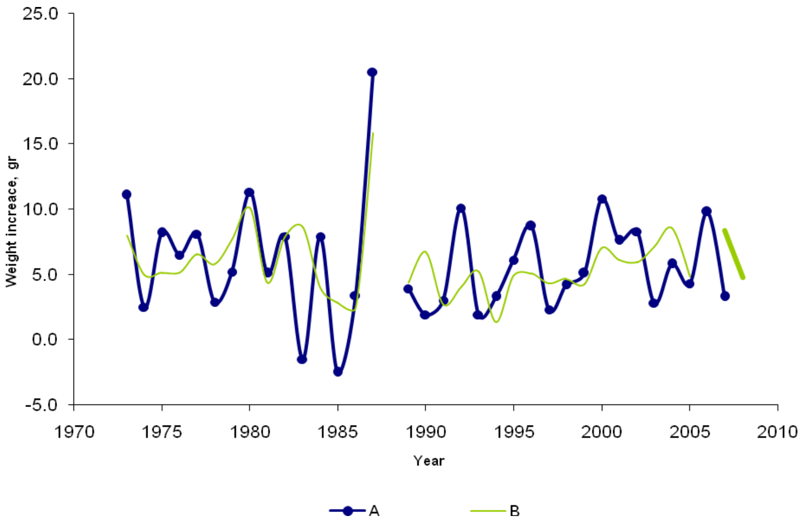

Figure 5.6. Year-to-year variability in weight increments of capelin aged 3+ (A) and results of statistical modelling (B).

5.2.3 Multispecies models

Development of multispecies models designed to improve fisheries management in the Barents Sea is based on species interactions started in the mid 1980s. The first ones were MULTSPEC, AGGMULT and SYSTMOD in IMR and MSVPA in PINRO (Tjelmeland and Bogstad, 1998; Hamre and Hatlebakk, 1998, Korzhev and Dolgov, 1999). In total these models contained the species cod, capelin, herring, haddock, arctic cod, shrimp, harp seal and minke whale. Later, the development of these models has been discontinued. However, these models were predecessors for the new models: EcoCod, Bifrost, Gadget and STOCOBAR. Benefits of multispecies models include: improved estimates of natural mortality and recruitment; better understanding of stock-recruit relationships and variability in growth rates; alternative views on biological reference points. Brief descriptions of the latter multispesies models, are given below.

5.2.3.1 EcoCod

This model has been developed since 2005 as the main task of the first stage of the joint PINRO-IMR Programme of Estimation of Maximum Long-Term Yield of North-East Arctic Cod taking into account the effect of ecosystem factors (Filin and Tjelmeland, 2005). This 10-year research programme was initiated at the Russian-Norwegian Fishery Commission's request. EcoCod is a stepwise extension of a single species model for cod (CodSim; Kovalev and Bogstad, 2005), where cod growth, maturation, cannibalism and recruitment are 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 modelling of recruitment in the capelin sub-model.

5.2.3.2 Bifrost

The Bifrost (Boreal integrated fish resource optimization and simulation tool) is a multispecies model for the Barents Sea (Tjelmeland, 2005), with its main emphasis on cod-capelin dynamics. The prey items for cod are cod, capelin and other food. Bifrost is used in connection with management of capelin by furnishing the tool used for calculating capelin quotas – CapTool – with historic replicates of parameters in the model for cod preying on capelin during January-March and parameters in the capelin maturation function, all of which are estimated in Bifrost.

The recruitment functions for cod and capelin are defined with the possibility of different forms, different probability functions for the error distribution, different parts of the year for using temperature data and different covariates including temperature, herring (for capelin recruitment) and cannibalism. For capelin, the influence from herring is invariably a covariate in the best recruitment relations, for cod temperature is invariably a covariate.

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

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

5.2.3.3 Gadget

A multi-species Gadget age-length structured model (www.hafro.is/gadget ; Begley and Howell, 2004, developed during the EU project dst^2 (2000-2003)), is being used for modeling the interactions between cod, herring, capelin and minke whale in the Barents Sea as part of the EU projects BECAUSE (2004-2007) and UNCOVER (2006-2010). This is a multi-area, multi-species model, focusing on predation interactions within the Barents Sea. The predator species are minke whale and cod, with capelin, immature cod, and juvenile herring as prey species. Krill is included as an exogenous food for minke whales. The cod model employed is based on the model presented at AFWG. So far, the model has been fitted to historical data on feeding, stock abundance and catches for the period 1985-2005. The results of model-data fit in stock abundance and whale diet composition can be found in the last year joint PINRO/IMR report on the Barents Sea ecosystem.

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

5.2.3.4 STOCOBAR

The STOCOBAR (STOck of COd in the BARents Sea) is a fish-ecosystem coupled model that describes stock dynamics of cod in the Barents Sea, which takes into accounts trophic interactions and environmental influence (Filin, 2005). It can be used for predictions and historical analysis of cod stock development as well as for estimation of effectiveness of different harvest and rebuilding strategies.

The STOCOBAR model has no geographical resolution, i. e. the processes are simulated without area differentiation. The time-step of the model can be set to either one year or half a year. The model includes cod as predator and seven prey species of cod; capelin, shrimp, polar cod, herring, krill (euphausiids), haddock and young cod (cannibalism). The species structure of the model is not permanent, and it is set according to the tasks of the model analysis and available input data. It can be reduced from the seven-species version to a simple version, which includes cod and capelin only. All calculations for cod in the model are carried out in cohort mode. The recruitment function is used for cod only. The results of model-data fit in cod diet composition can be found in the last year joint PINRO/IMR report on the Barents Sea ecosystem (Stiansen J.E. and A.A. Filin (editors), 2007).

Long-term estimations of the influence of ecosystem factors on the cod stock development are realized in the model by using stochastic ecosystem scenarios (Filin and Tjelmeland, 2005).

The first version of STOCOBAR was developed at PINRO in 2001, and improvement of this model is continuing. The description of the model algorithms is in the working documents of the AFWG in 2007 (Filin 2007). The work on the development of the STOCOBAR model is part of the Barents Sea Case Study within the EU project UNCOVER (2006-2010) and the joint PINRO-IMR Program of Estimation of Maximum Long-Term Yield of North-East Arctic Cod taking into accounts the effect of ecosystem factors.

5.2.4 Including data on cod predation into stock assessment of cod and haddock

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

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

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

5.2.5 Models for simulation the drift of fish eggs and larvae

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

6 Impacts of the fisheries on the ecosystem

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

Fishing is the largest human impact to the fish stocks in the Barents Sea, and thereby the functioning of the whole ecosystem. However, the observed variation in both fish species and ecosystem is also impacted by other effects such as climate and predation (e.g. see Table 2.4 for predation by minke whale and harp seal). In the Barents Sea the catch of the major fish species by the fishing fleet in 2007 was about 900 000 tonnes.

6.1 General description of the fisheries

The major demersal stocks in the Northeast Arctic include cod, haddock, saithe, and shrimp. In addition, redfish, Greenland halibut, wolffish, and flatfishes (e.g. long rough dab, plaice) are common on the shelf and at the continental slope, with ling and tusk also found at the slope and in deeper waters. In 2007, catches of nearly 900 thousand tonnes (provisional figures) are reported from the stocks of cod, haddock, saithe, redfish, and Greenland halibut, which is a decrease of 7% as compared to 2006. An additional catch of about 40 000 tonnes was taken from the stocks of wolfish and shrimp. The annual fishing mortalities F (the mortality rate is linked to the proportion of the population being fished by $1-e^{-F}$) for the assessed demersal fish stocks show large temporal variation within species and large differences across species from 0.1 (≈10% mortality) for some years for *Sebastes marinus* to above 1 (≈63% mortality) for some years for cod (Figure 6.1). The major pelagic stocks are capelin, herring, and polar cod. There was no fishery for capelin in the area in 2004-2007 due to the stock's poor condition, and there was 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 these species in the area. Species with relatively small landings include salmon, halibut, hake, pollack, whiting, Norway pout, anglerfish, lumpsucker, argentines, grenadiers, flatfishes, horse mackerel, dogfishes, skates, crustaceans, and molluscs.

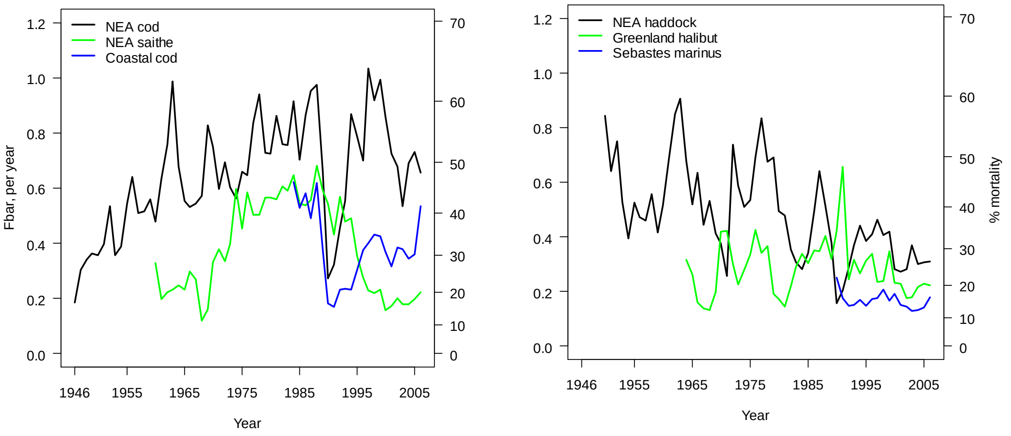

Figure 6.1. *Time series of annual average fishing mortalities for Northeast Arctic cod (time period 1946-2006, average for ages 5-10), Northeast Arctic saithe (time period 1960-2006, average for ages 4-7), coastal cod (1984-2006, average for ages 4-7), Northeast Arctic haddock (time period 1950-2006, average for ages 4-7), Greenland halibut (time period 1964-2006, average for ages 6-10) and Sebastes marinus (time period 1990-2006, average for ages 12-19).*

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

For most of the exploited stocks an agreed quota is decided (TAC). In addition to an agreed quota, a number of additional regulations are applied. The regulations differ among gears and species and may be different from country to country, and a non-exhaustive list as well as a description of the major fisheries in the Barents Sea by species can be found in Table 6.1.

Table 6.1. 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 2007 (tonnes)**	**As by-catch in fleet(s)**	**Location**	**Agreements and regulations**
Capelin	PS, TP	seasonal	4[B]	TR, TS	Northern coastal areas to south of 74°N	Bilateral agreement, Norway and Russia
Coastal cod	GN, LL, HL, DS	all year	23 841[C]	TS, PS, DS, TP	Norwegian coast line	Q, MS, MCS, MBU, MBN, C, RS, RA
Cod	TR, GN, LL, HL	all year	486 883[C]	TS, PS, TP, DS	North of 62°N, Barents Sea, Svalbard	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Wolffish[2]	LL	all year	13 401[E]	TR, (GN), (HL)	North of 62°N, Barents Sea, Svalbard	Q, MB
Haddock	TR, GN, LL, HL	all year	146 830	TS, PS, TP, DS	North of 62°N, Barents Sea, Svalbard	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Saithe	PS, TR, GN	seasonal	197 334	TS, LL, HL, DS, TP	Coastal areas north of 62°N, southern Barents Sea	Q, MS, SG, MCS, MBU, MBN, C, RS, RA
Greenland halibut[4]	LL, GN	seasonal	14 828	TR	Deep shelf and at the continental slope	Q, MS, RS, RG, MBH, MBL
Sebastes mentella	No directed fishery	all year	19 828	TR	Deep shelf and at the continental slope	C, SG, MB
Sebastes marinus	GN, LL, HL	all year	7 187	TR	Norwegian coast	SG, MB MCS, MBU, C
Shrimp	TS	all year	25 919[E]		Svalbard, Barents Sea, Coastal	ED, EF, SG, C, MCS

[A] Provisional figures

[B] On a research quota

[C] The total cod catch north of 62 N (499,247 t) is the sum of the NEA cod catch given in the table and the total cod catches between 62ºN and 67ºN for the whole year and between 67ºN and 69ºN for the second half of the year (12,364 t).

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

[E] Norwegian and Russian landings

6.2 Mixed fisheries

The demersal fisheries are highly mixed, usually with a clear target species dominating, and with low linkage to the pelagic fisheries (Table 6.2). Although the degree of mixing may be high, the effect of the fisheries varies among the species. More specifically, the coastal cod stock and the two redfish stocks are presently at very low levels. Therefore, the effect of the mixed fishery will be largest for these stocks. In order to rebuild these stocks, further restrictions in the regulations should be considered (e.g. closures, moratorium, and restrictions in gears).

Successful management of an ecosystem includes being able to predict the effect 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 are largely missing due to a need for improving methodology combined with lack of necessary data. However, technical interactions between the fisheries can be explored by the correlation in fishing mortalities among species. The correlation in fishing mortality is positive for Northeast Arctic cod and coastal cod, and for haddock and coastal cod confirming the linkage in these fisheries (Figure 6.2). There is also a significant relationship between saithe and Greenland halibut although the linkage in these fisheries is believed to be low (Table 6.2). The relationships between the other fishing mortalities are scattered and inconclusive. In case of strong dependencies in fishing mortalities this method can in principle be used to produce consistent advice across species concerning fishing mortality. It is however too simple since this correlation is influenced by too many confounding factors whose effect cannot be removed without a detailed analysis of data with a higher resolution (e.g. saithe and Greenland halibut, Figure 6.2) 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. The composition of cod, haddock, saithe, Greenland halibut, *Sebastes marinus*, *Sebastes mentella* and other species caught by the Russian and Norwegian trawl fleet shows spatial differences in both catch compositions and catch sizes as well as large differences between the countries Figure 6.3-Figure 6.6 shows the 2007 catches. (For the catch distributions in 2005 and 2006, see ICES/AFWG 2007). In the north eastern part of the Barents Sea the major part of the Russian catches consists of cod, whereas the Norwegian catches include a large proportion of other species (mainly shrimp). In the most western part of the Barents Sea, the Norwegian catches consist of *Sebastes mentella* and Greenland halibut in addition to cod, whereas the Russian catches mainly consist of cod and haddock. The main reason for this disparity is the difference in spatial resolution of the data; the Norwegian strata system extends further west and thus covers the fishing grounds for Greenland halibut, whereas 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 are more dominant in the catches (e.g. saithe).

Estimates of unreported catches of cod and haddock in 2002-2007 indicate that this is a considerable problem (ICES/AFWG 2008). Discarding of cod, haddock and saithe is thought to be significant in periods although discarding of these, and a number of other species, is illegal in Norway and Russia. Data on discards are scarce, but attempts to obtain better quantification are ongoing.

Table 6.2. Flexibility in coupling between the fisheries. Fleets and impact on the other species (H, high, M, medium, L, low and 0, nothing). The table below the diagonal indicates what gears couples the species, and the strength of the coupling is given above the diagonal. The gears are abbreviated as: 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	

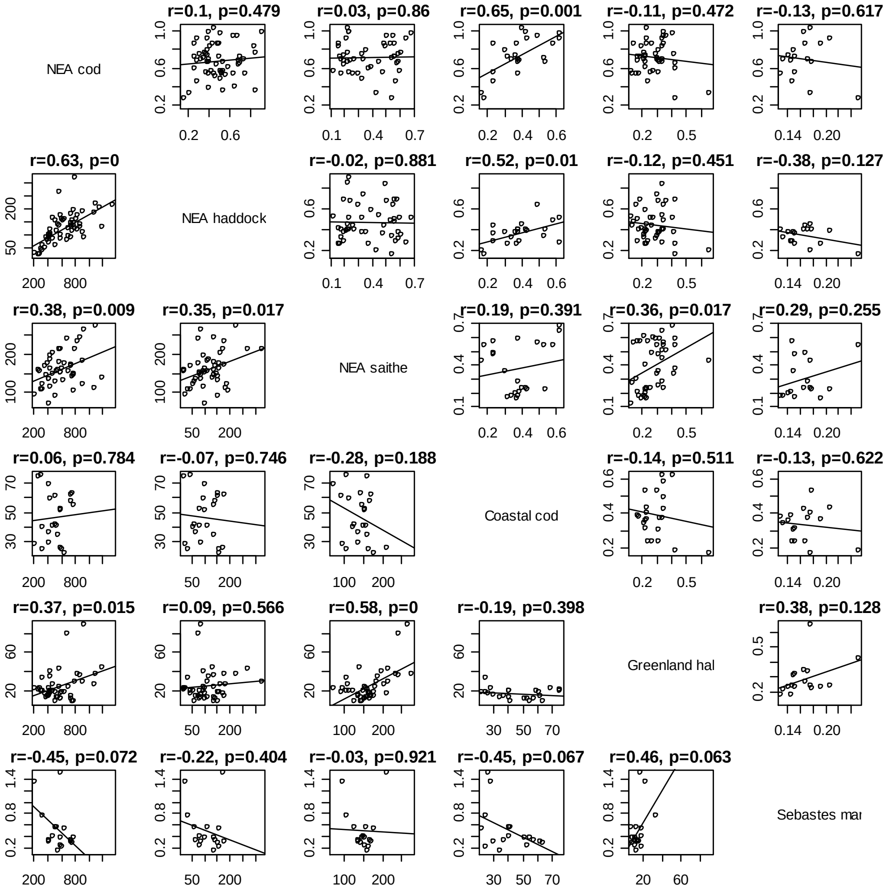

Figure 6.2. Pair-wise plots of annual average fishing mortalities (above diagonal) and landings (below diagonal) for overlapping time periods for Northeast Arctic cod (time period 1946-2006, average for ages 5-10), Northeast Arctic haddock (time period 1950-2006, average for ages 4-7), Northeast Arctic saithe (time period 1960-2006, average for ages 4-7), coastal cod (1984-2006, average for ages 4-7), Greenland halibut (time period 1964-2006, average for ages 6-10) and Sebastes marinus (time period 1987-2006, average for ages 12-19). The correlation and the corresponding p-value are given in the legend.

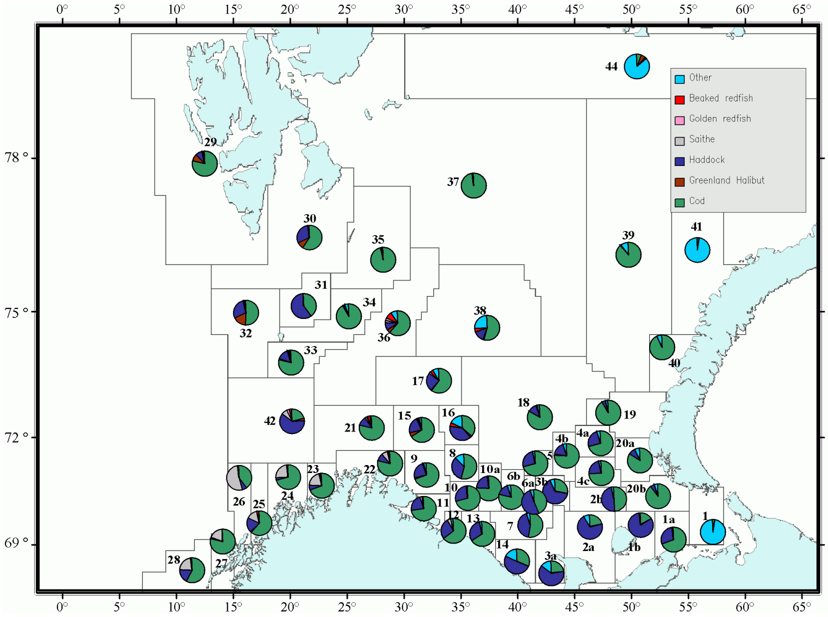

Figure 6.3. Relative distribution by weight of cod, haddock, saithe, Greenland halibut, golden redfish (Sebastes marinus), beaked redfish (Sebastes mentella) and other species taken by Russian bottom trawl in 2007 per main area for the Russian strata system.

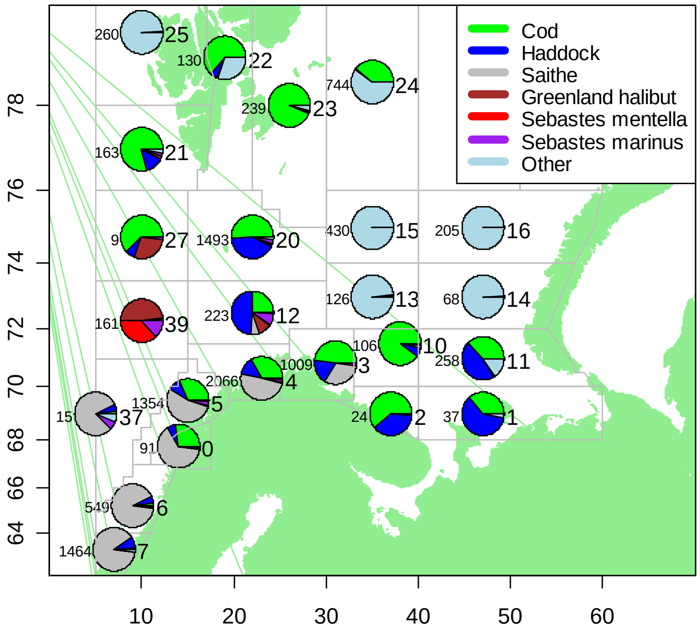

Figure 6.4. Relative distribution by weight of cod, haddock, saithe, Greenland halibut, Sebastes marinus (golden redfish), Sebastes mentella (beaked redfish) and other species taken by Norwegian bottom trawl in 2007 per main area for the Norwegian strata system. The large number to the right of each pie diagram is the name of the stratum, while the small number to the left is the number of vessel days recorded in this area.

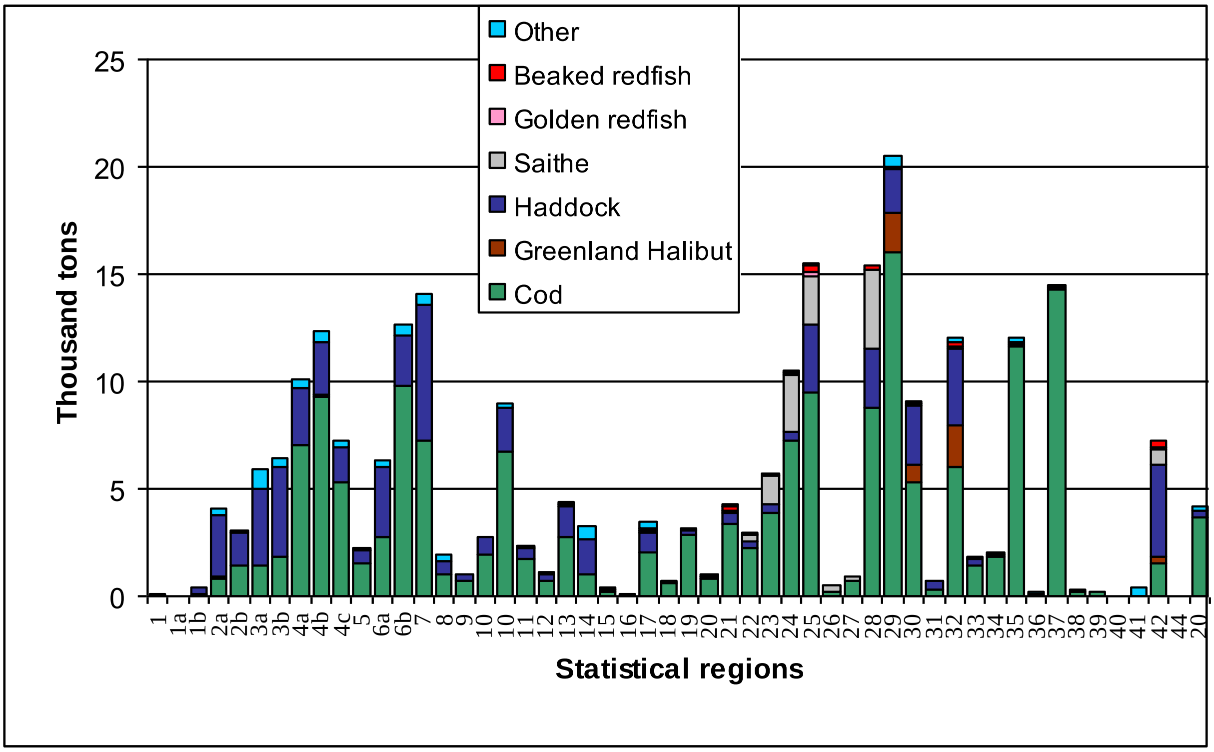

Figure 6.5. The Russian catch of cod, haddock, saithe, Greenland halibut, Sebastes marinus, Sebastes mentella and other species taken by bottom trawl by main statistical areas in 2007, thousand tonnes. The statistical areas correspond to the areas shown in Figure 6.3.

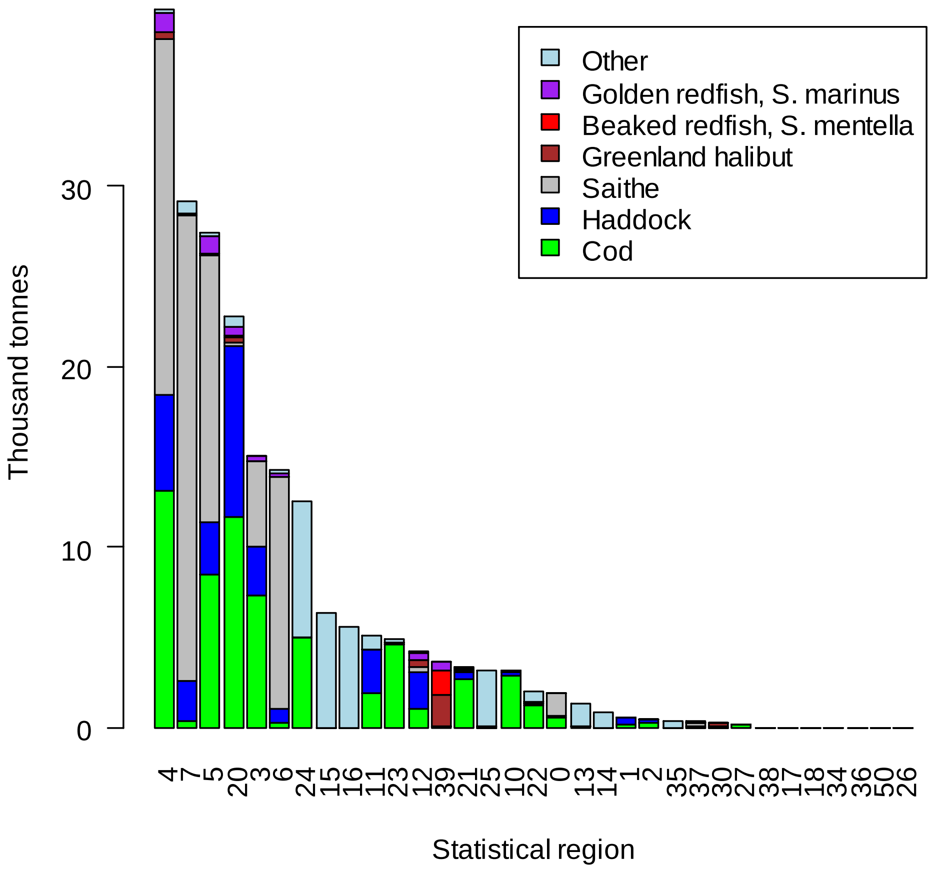

Figure 6.6. The Norwegian catch of cod, haddock, saithe, Greenland halibut, Sebastes marinus, Sebastes mentella and other species taken by bottom trawl by main statistical areas in 2007, thousand tonnes. The statistical areas correspond to the areas shown in Figure 6.4.

6.3 Other issues

In order to conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. In general, the response of benthic organisms to disturbance differs with substrate, depth, gear, and type of organism (Collie et al. 2000). Seabed characteristics from the Barents Sea are only scarcely known (Klages et al. 2004) and the lack of high-resolution (±100 m) maps of benthic habitats and biota is currently the most serious impediment to effective protection of vulnerable habitats from fishing activities (Hall 1999). An assessment of fishing intensity on fine spatial scales is critically important in evaluating the overall impact of fishing gear on different habitats and may be achieved, for example, by satellite tracking of fishing vessels (Jennings et al. 2000).The challenge for management is to determine levels of fishing that are sustainable and not degradable for benthic habitats in the long run.

The qualitative effects of trawling have been studied to some degree. The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. Barents Sea hard bottom substrata, with associated attached large epifauna should therefore be identified.

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 (ghost fishing). The catch efficiency of lost gillnets has been examined for some species and areas, but at present no estimate of the total effect is available. Other types of fishery-induced mortality include burst net, and mortality caused by contact with active fishing gear, such as escape mortality (Suuronen 2005; Broadhurst et al 2006; Ingólfsson et al 2007). Some small-scale effects are demonstrated, but the population effect is not known.

The harbour porpoise is common in the Barents Sea region south of the polar front and is most abundant in coastal waters. The harbour porpoise is subject to by-catches in gillnet fisheries (Bjørge and Kovacs 2005). In 2004 Norway initiated a monitoring program on by-catches of marine mammals in fisheries. 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.

7 Levels and impact of pollution on the ecosystem

By S. Boitsov (IMR), J. Klungsøyr (IMR), N.F. Plotitsyna (PINRO) and A. Yu. Zhilin (PINRO)

7.1 Overview

The Barents Sea is no longer a pristine environment due to various human activities such as fishing, oil exploration, and ship traffic that are increasing in many parts of the sea. It remains relatively clean, however, when compared to marine areas in many industrialized parts of the world. Major sources of contaminants in the Barents Sea are natural processes, long-range transport, accidental releases from local activities, and ship fuel emissions.

Organic contaminants are often poorly soluble in water and are lipophilic. This may result in their sorbtion to organic material like plankton, their uptake by marine biota, eventual burial in the sediments, and becoming a sink for contaminants. Benthic fauna may thus be exposed to higher contamination levels than fauna dwelling in higher water layers. Ingestion of contaminants by various sediment-filtering organisms may lead to bioaccumulation of contaminants in tissues of species that are higher in the food chain.

Polyaromatic hydrocarbons (PAH) are organic contaminants which play a significant role in the Barents Sea. High PAH levels may be due to natural processes such as erosion of coal-bearing bedrock at Svalbard (Spitsbergen), or due to seepages of oil and gas from the seabed. Anthropogenic sources of hydrocarbons may play a less important role in the Barents Sea, although increasing oil exploration and shipping — combustion of ship fuel and long-range transport may also contribute to elevated levels of PAH — activities require regular monitoring for levels of contamination.

Other types of contaminants — particularly persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs), Dichloro-Diphenyl-Trichloroethane (DDT) etc. — primarily have anthropogenic sources; long-range transport (both by air and with sea currents) of such contaminants may result in their increased levels in the Barents Sea. Monitoring of these contaminants is necessary to document current levels, and to evaluate the efficiency of international input reduction measures.

7.2 Sampling

Samples of sediments were collected by IMR in 2006 during a scientific survey in the Tromsøflaket area of the south-western Barents Sea onboard R/V Håkon Mosby — part of mapping activities conducted under the MAREANO project — for evaluation of contaminants like oil tetrahydrocannabinol (THC) and polyaromatic hydrocarbons (PAH) in sediments.

Sediment samples were also collected by PINRO during the ecosystem survey onboard R/V *Fridtjof Nansen* and R/V *Smolensk* (August-September, 2006) using multicorer gear at 9 open-sea stations and 4 close-to-shore/fjord stations in the south-western part of the Barents Sea — between ca. 70^{o} and 72^{o} North and 21^{o} and 23^{o} East (Figure 7.1 and Figure 7.2).

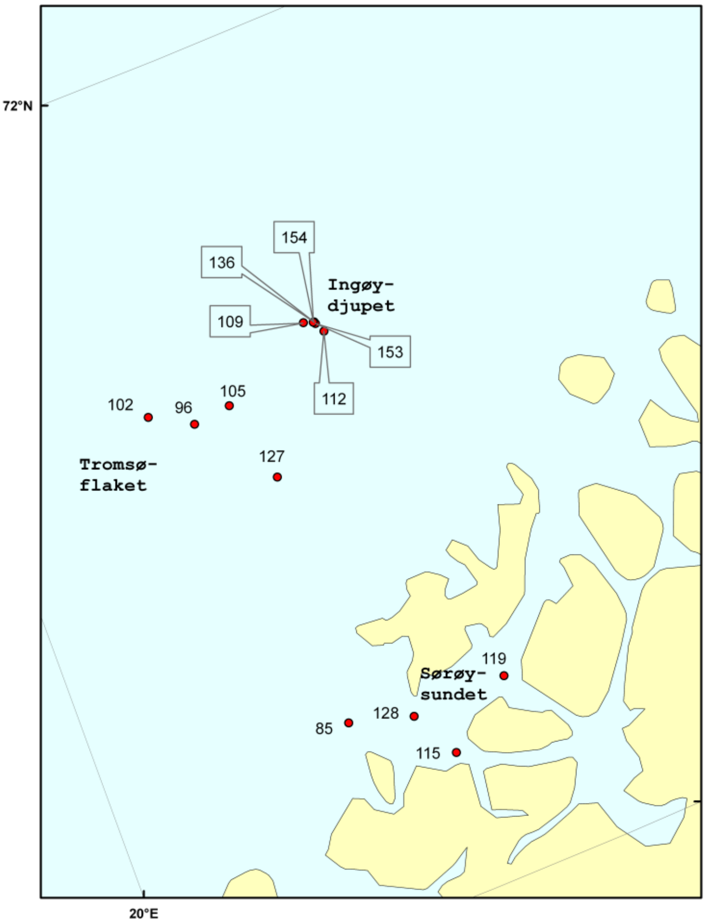

Figure 7.1. Multicorer sampling stations of the 2006 IMR survey onboard R/V Håkon Mosby).

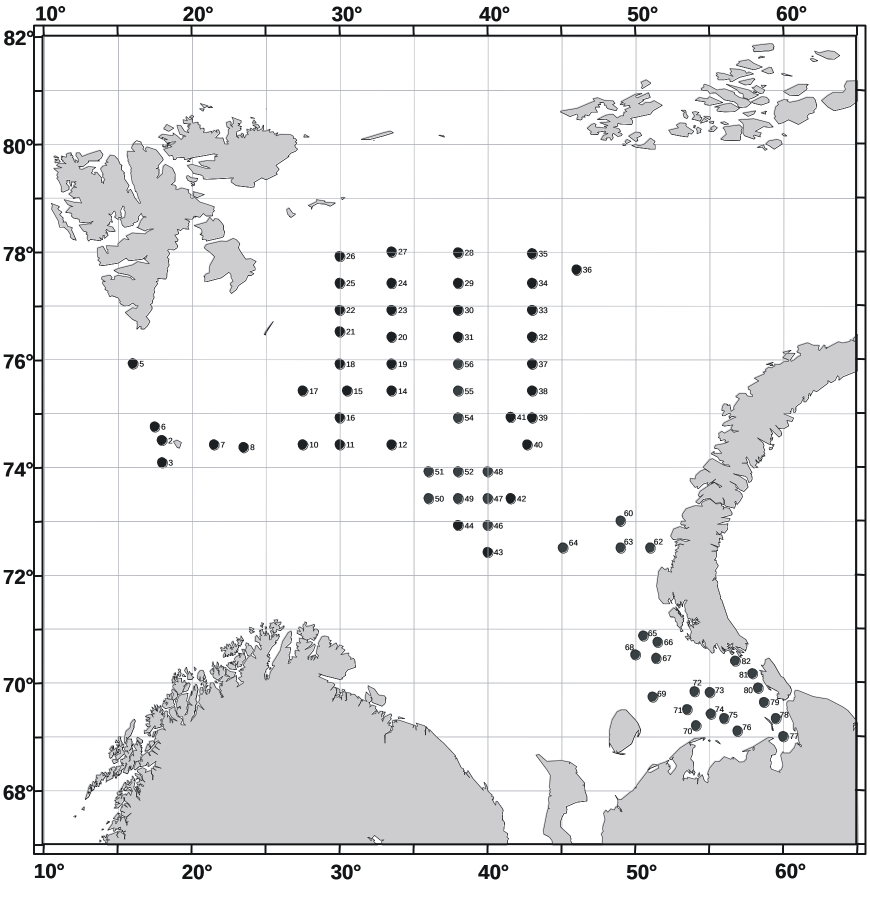

Figure 7.2. Sediment grab sample stations collected by PINRO during 2006 Ecosystem Survey in the Barents Sea).

7.3 Contaminants in fish

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

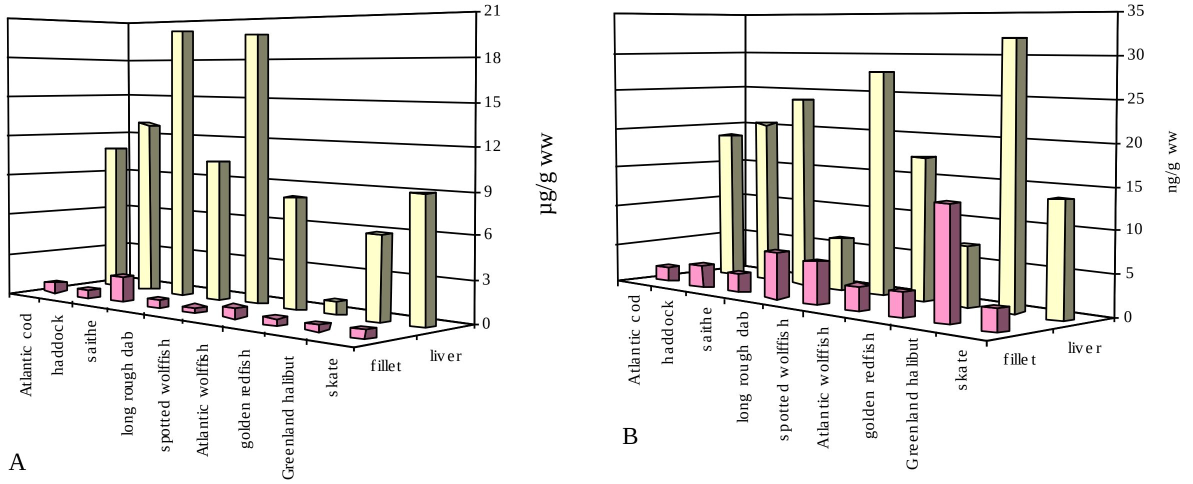

Figure 7.3. The concentrations of n- paraffin (A) and sum PAH (B) in fish.

Combined concentrations of organochlorine pesticides and polychlorinated biphenyls in muscle tissue of fish from the Barents Sea did not exceed the permitted levels approved by the Russian sanitary code for raw food products and provisions (Figure 7.3). Residues of hexachlorocyclohexane, hexachlorobenzene, and chlordanes in the muscles of fish fish examined did not exceed 2 ng/g wet weight (ww). DDT (and its metabolites) was the dominant pesticide found in the muscles of fish examined. Tetra-, penta- and hexachlorobiphenyls (congeners 52, 118, 138, 153) constituted 90 % of total PCBs. High concentrations of p,p'-DDE compared to other isomers found in fish muscles , indicates that DDT transformation occurs over time.

Concentrations of organochlorine pesticides and PCBs in livers of fish from the Barents Sea presented in Figure 7.4 indicate that DDT (and its metabolites) was dominant; followed by the isomers of chlordane, hexachlorocyclohexane, and hexachlorobenzene. The composition of individual PCBs in the livers of fish examined was dominated by congeners 153, 138, 118; this could indicate that commercial mixtures of Aroclor-type PCBs (Russian analogues: sovol and sovtol) were important sources of contamination.

Iron was the dominant metal found in fish muscle tissue. Concentration of nickel, chromium, cobalt, lead, and cadmium in the muscles of all fish examined were below detectable limits.. Concentrations of copper, zinc, and mercury varied within a very narrow range, and corresponded to natural background levels. Concentrations of cadmium in livers of all fish examined did not exceed the permissible level for consumption (0.7 µg/g ww). One exception was Atlantic wolfish; concentration of cadmium in its liver twice exceeded the standard. Concentrations of arsenic in individual samples from muscles of cod, sand-dab, wolfish, haddock, and thorny skate exceeded the established standard of 5.0 µg/g ww.

Concentrations of n- paraffins predominated in muscle and liver tissue fish, with a pattern characteristic of saturated aliphatic hydrocarbons of biogenic origin. Results from this investigation indicate low levels of PAH in Barents Sea fish species. Concentrations of chlorinated hydrocarbons and high metals (lead, cadmium and mercury) in fish muscle and liver tissue was well below allowable levels. Concentration of arsenic in muscle tissue for a number of species exceeded established standards.

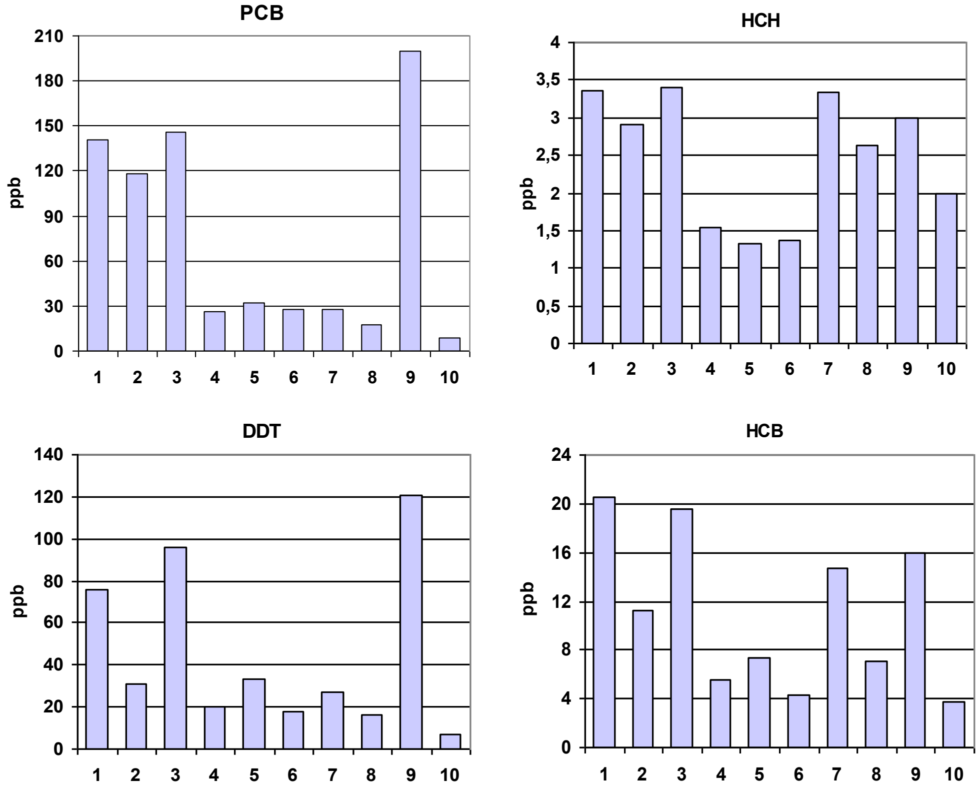

Figure 7.4. Average concentrations (ng/g wet weight) of PCBs (sum of CB congeners no 28, 52, 101, 118, 138, 153, 180), HCHs (sum alpha-, gamma-HCH), DDTs (sum p,p,-DDE, o,p,-DDD, p,p,-DDD, o,p,-DDT, p,p,-DDT), HCB in liver of Atlantic cod (Gadus morhua) (1), haddock (Melanogrammus aeglefinus) (2), saithe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

7.4 Contaminants in sediments

Samples collected by IMR in Tromsøflaket, indicate levels of PAHs in surface sediments that vary between locations from 58,8 to 326 ng/g dwt when concentrations of all compounds examined are summed; this includes 22 separate PAH compounds, and 8 groups of alkylated PAH compounds (further denoted as Sum PAH). Observed variations in concentration are explained by differences in deposition of compounds examined, or by the influence of local sources (such as natural seepages of oil or other organic fossils). Both variation and overall values are lower than observed in earlier studies of the entire Norwegian section of the Barents Sea (IMR-PINRO Report, 2007), with mean values for Sum PAH being 194 ng/g d.w., in contrast to 414 ng/g d.w. measured in 2004. Decreased values can be explained by the absence of significant local sources, of either natural or anthropogenic origin; there are no significant oil seepages or human activities in the area studied.

Levels of the carcinogen, benzo[a]pyrene, had 3.7 ng/g dw as mean value, and never exceeded 7,5 ng/g dw . This level (below 10 ng/g dw) is classified as insignificant-or-little contamination by the Norwegian Pollution Authority.

The levels of benzo[a]pyrene, the compound of concern due to its carcinogenicity, had 3,7 ng/g d.w. as the mean value and did not exceed 7,5 ng/g d.w. anywhere. Thus, it was within the limits of insignificant-or-little contamination (below 10 ng/g dry weight) by classification of the Norwegian Pollution Authority.

Levels of total hydrocarbons (THC) in surface sediments ranged from 1,9 to 14,6 µg/g dw, with mean value of 6,3 µg/g dw. This was significantly lower than levels measured throughout the Barents Sea during 2004, which ranged from 50-70 µg/g dw in the Svalbard region (Stiansen and Filin 2007).

Geographically, the highest Sum PAH and THC values were observed in the fjord areas (Figure 7.5), possibly influenced by human activities such as shipping. Anthropogenic influence is here assessed as a ratio between concentrations of phenanthrene and anthracene (PHE/ANT) in samples. PHE/ANT ratios below 10 signify a possible anthropogenic influence, while ratios above 10 indicate no such influence. Samples taken from fjord areas all had PHE/ANT<10, while samples from open sea areas had PHE/ANT close to or >10. This confirms that contribution to observed higher PAH levels in fjord areas are related to human activities, while higher PAH levels in open-sea areas are of natural origins.

Areas studied in the south-western Barents Sea represent clean environments, with minimal influence from human activities. Observed PAH levels are primarily due to complex sedimentation processes, can be used to establish critical reference point on background levels in this area, before oil exploration begins in the near future.

PINRO found concentrations of aliphatic hydrocarbons in upper layers of bottom sediments that varied from 0.13 to 0.5 µg/g dw in western and central regions, and from 0.3 to 3.3 µg/g dw in the south-eastern region of the Barents Sea (Figure 7.6). *N*-paraffins were represented by a wide range of hydrocarbons, from C_{11} to C_{30}.

Prystane (iC_{19}) and phytane (iC_{20}) were identified isoprenoides;the relation between them can be used as a fractional conversion marker for the nature and condition of hydrocarbons in bottom sediments. The fact that hydrocarbons of biogenic origin dominate in aliphatic compounds is demonstrated by their ratio: prystane/phytane >2. There are no specific guidelines regarding *n*-paraffin concentrations in bottom sediments.

Total *n*-paraffin levels in bottom sediments of Barents Sea fishing areas studied were below the 340 µg/g dw background level indicating anthropogenic influence; this level is representative for upper layers of bottom sediments on the western Arctic Shelf.

Total polycyclic aromatic hydrocarbons (PAHs) (19 EPA Protocols 8310 PAHs + perylene + 1-, 2-methylnaphthalene), in bottom sediment samples from the Barents Sea, ranged from 37.3 to 689 ng/g dw (Figure 7.7).

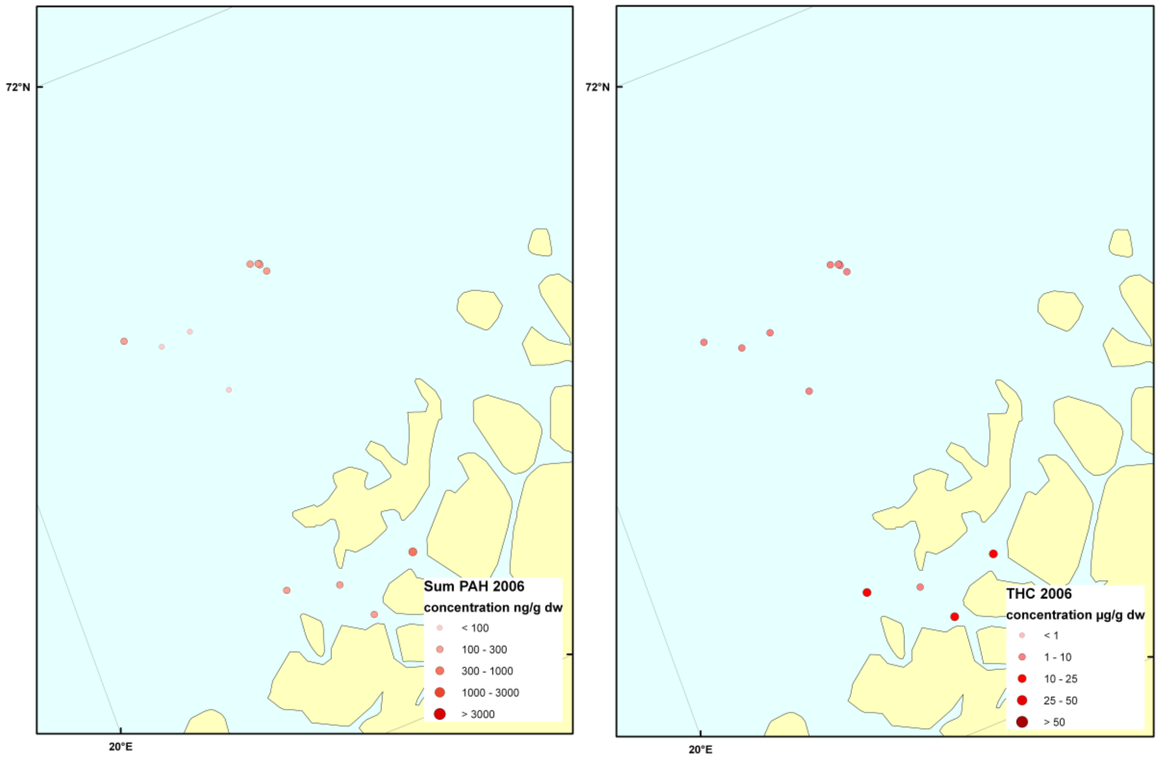

Figure 7.5. Levels of hydrocarbons in surface sediments at the studied locations. Left panel is Sum PAH levels (ng/g dry weight). Right panel is THC levels (µg/g dry weight).

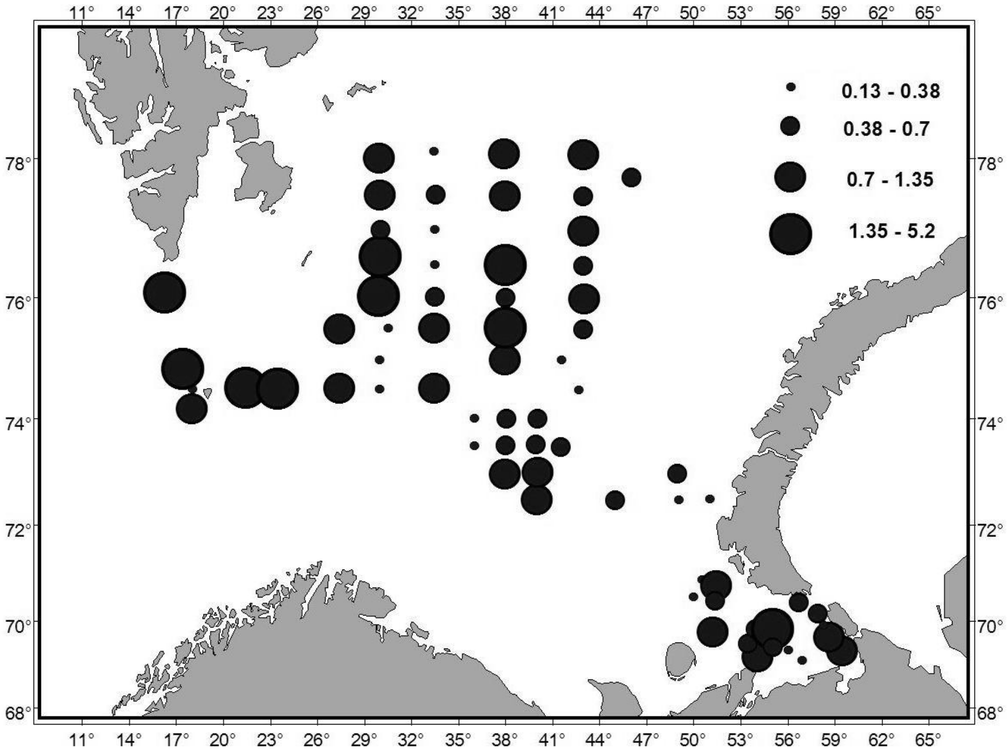

Figure 7.6. Concentrations of n-paraffin in bottom sediments (µg/g dw).

Peak PAH levels were recorded at Stations 5, 6, 7 and 8, with concentrations being 689, 433, 514, and 570 ng/g dw,t respectively. Total carcinogenic PAH content (ΣCPAHs) [benzo(a)anthracene, benzo(b)fluoranthene, benzo(b)fluoranthene, benzo(a)pyrene, indeno-(1,2,3-cd)pyrene, and dibenzo(a,h)anthracene] varied from 13.73 ng/g dw (Station 65) to 289.0 ng/g dw (Station 5), and comprised 23-54% of ΣPAHs. Highest ΣCPAH concentrations were found in sediments at Stations 5 and 72. The total toxic benzo(a)pyrene equivalent for bottom sediment samples examined varied from 1.77 ng/g dw (Station 65) to 37.77 ng/g dw (Station 5). Contributions of different PAHs to the total toxic benzo(a)pyrene equivalent decreased in the following order: benzo(a)pyrene (24.9%); benzo(b)fluoranthene (23.2%); indeno(1,2,3-cd)pyrene (15.5%); benzo(a)anthracene (3.3%); dibenzo(a,h)anthracene (31.8%); and benzo(k)fluoranthene (1.3%).

At the majority of stations in the area under study, Naphthalene, 2-methylnaphthalene, phenanthrene, benzo(b)fluoranthene, perylene, indeno(1,2,3-cd)pyrene were predominant individual PAHs in bottom sediments; total amount of each ranged from 30 to 59% of the total PAH. A ratio of the sum of low molecular weight PAH concentrations (ΣLMW) to the sum of higher molecular weight PAH concentrations (ΣHMW) was used as criterion for PAH origin in Barents Sea bottom sediments., For the majority of stations, the ratio was below 1. This indicated that PAHs had formed as a result of fossil fuel burning.

Quantitative measures indicated low concentrations of PAHs in bottom sediments within areas studied; this was particularly true for central and southwestern areas of the Barents Sea.

In Russia, there were no specific classification guidelines for concentrations of contaminants in marine bottom sediments. . Norwegian guidelines accepted by the State Pollution Control Authority (SFT), deemed that ΣPAH and benzo(a)pyrene concentrations in bottom sediments at most stations within areas studied did not exceed background levels: < less 300 ng/g dw and < less 10 ng/g dw. Thus, PAH concentrations in the upper layers of bottom sediment in areas studied were at background levels. PAHs in upper layers of bottom sediments were mainly of pyrogenic origin.

Among organochlorine pesticides in the bottom sediments examined, ΣDDT residue levels (sum of *p,p*-DDE, *o,p*-DDD, *p,p*-DDD, *o,p*-DDD and *p,p*-DDD) were predominant. The total amount of DDT in bottom sediments exceeded anthropogenic background level (0.5 ng/g dw), and fell within the ‘moderately contaminant’ category (Figure 7.8).

Concentrations of polychlorinated biphenyls (PCBs) in bottom sediments of the Barents Sea did not exceed the anthropogenic background level of 5 ng/g dw (Figure 7.9). Individual congeners of PCBs —, numbers 138, 153 and 118 — widely used in industrial mixes, were predominant in upper layers of bottom sediments.

Concentrations of common heavy metals (Cu, Zn, Cr, Co, Pb, Cd, and Hg) in bottom sediments of areas studied were within the limits of natural background levels. Concentrations of Ni in bottom sediments at the majority of stations exceeded the natural background level (30 μg/g dw).

Results of this study indicate low level of contaminants in the Barents Sea marine environment and confirm results of earlier studies on bottom sediments in the same areas. Inthe near-term, observed levels of contaminants in the marine environment should not have significant impact on commercially important stocks in this area.

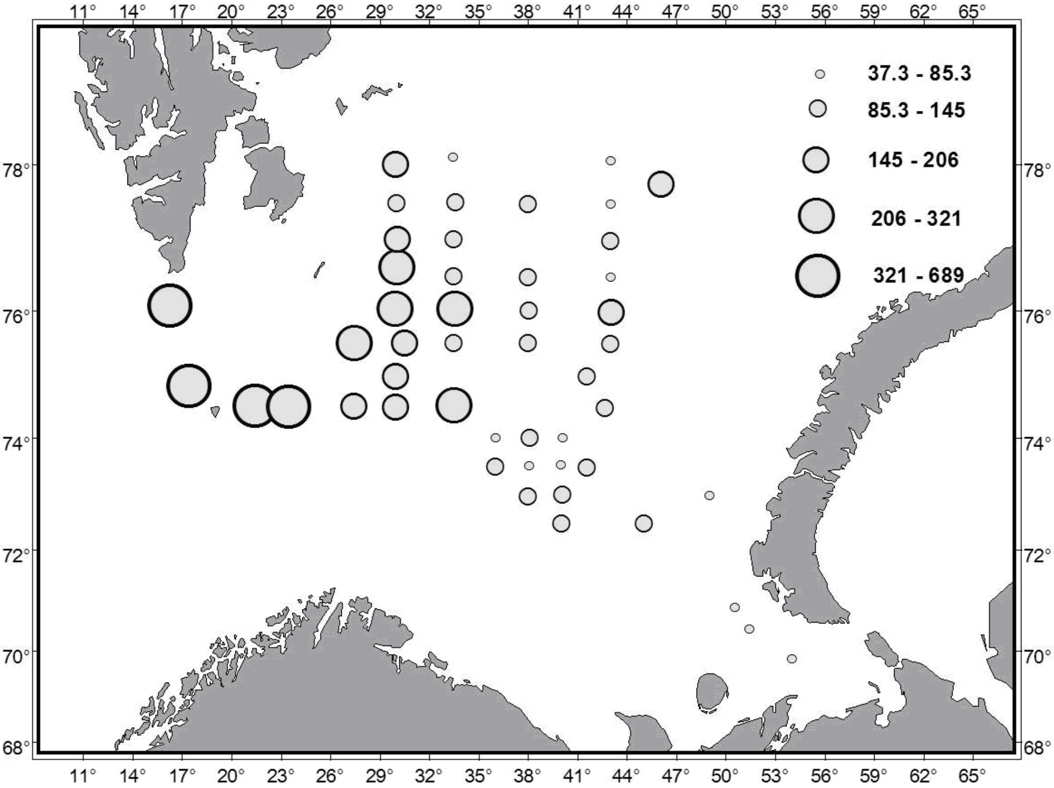

Figure 7.7. Concentrations ∑PAH in bottom sediments (ng/g dw).

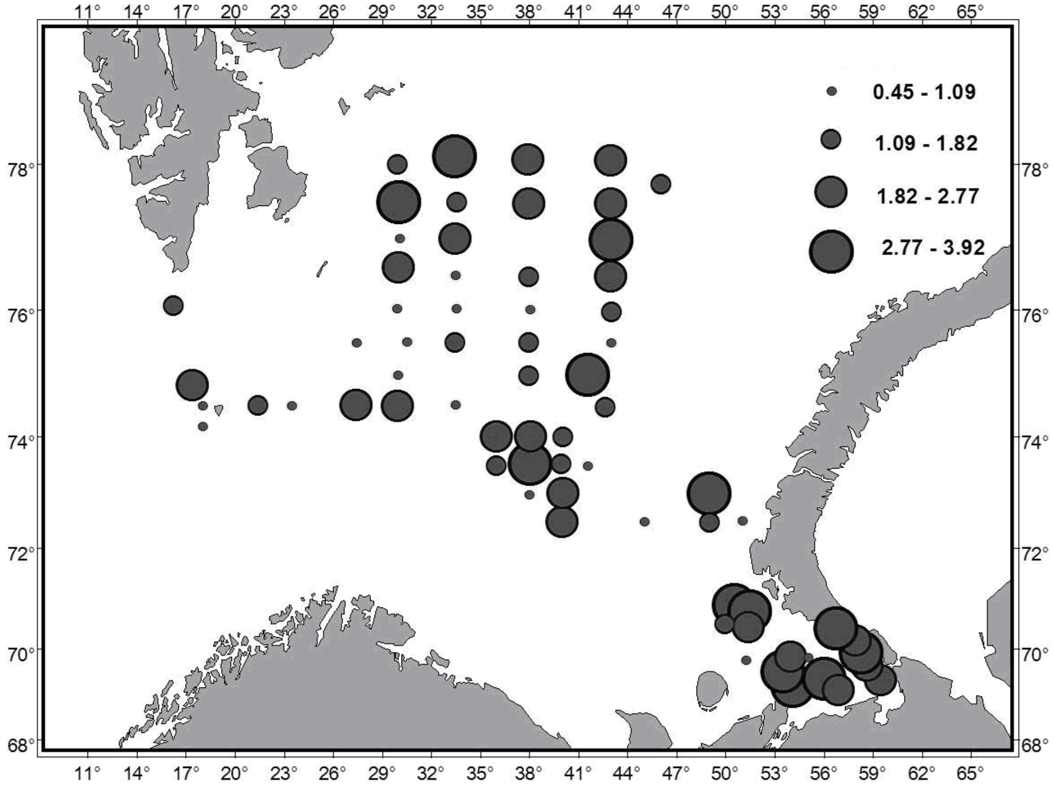

Figure 7.8. Concentrations of ∑DDT in bottom sediments (ng/g dw).

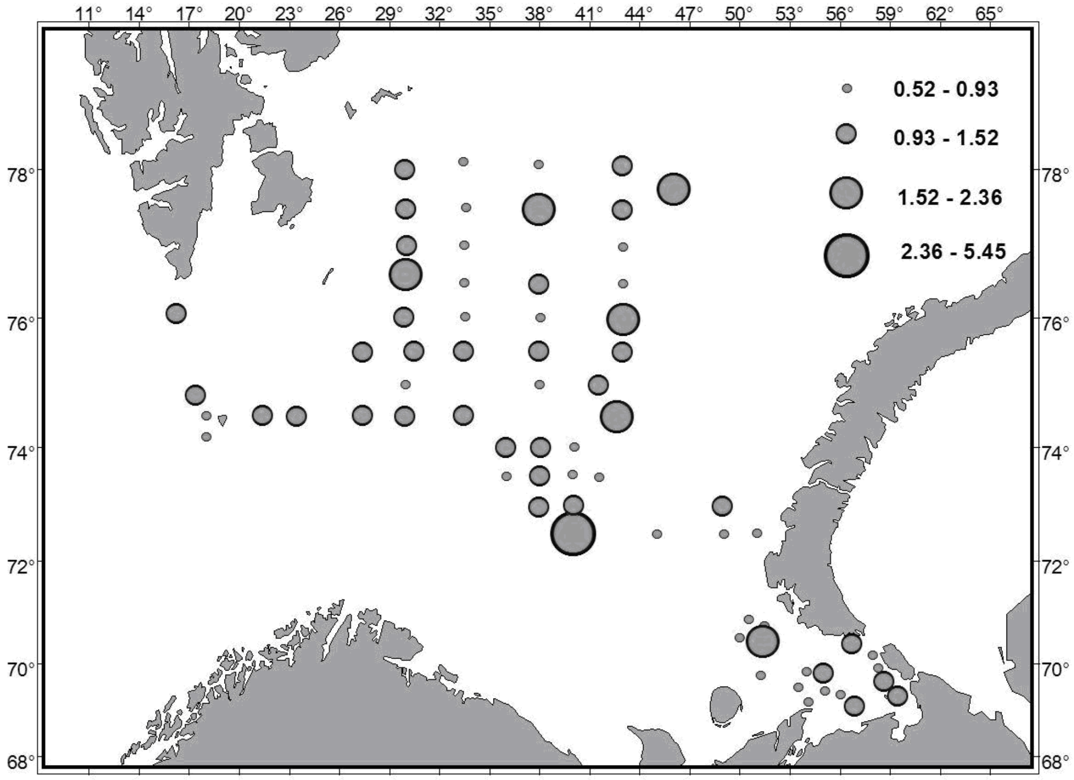

Figure 7.9. Concentrations of ∑PCB in bottom sediments (ng/g dw).

8 Risk on the ecosystem

By E. Olsen (IMR), O.V. Titov (PINRO) L.L. Jørgensen (IMR) and M.A. Novikov (PINRO)

Integrated management of all human activities to ensure ongoing ecosystem services is an underlying principle of the ecosystem approach to management (EAM). Traditionally, sector-based management has focused on the sector-based impacts on the ecosystem, and fishing — having been the most important and far-reaching human activity in the ecosystem — has been given most of the attention with analyses of impacts and risks. An effective EAM demands that we understand the risks associated with all other human activities, and their combined effect on the Barents Sea ecosystem. This need has increased in importance as oil- and gas industries have begun to develop new off-shore fields in the Barents Sea, and ship transport of oil and gas from the region has increased exponentially over the last 5 years.

This chapter gives a brief overview of risks posed by human activities, other than fishing, in the Barents Sea. Traditionally, risk has been defined as:

Risk = Likelihood × Consequence

But, can be expanded to include costs (economic damage):

R_E = Risk × DamageCost (Binenko and Berkovits, 2006)**.**

- We here discuss risk related to the following anthropogenic activities:Hydrocarbon extraction (exploratory drilling, production, platforms etc);
- Transport of raw and refined hydrocrabon products and the handling of cargo;
- Invasion of alien organisms as result of shipping.

8.1 Oil and gas production

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

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

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

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

The experience from laying the deep-water pipeline "Goluboj potok" ("Blue flow") (396 km along the bottom of the Black Sea), and from gas pipeline in the North Sea support the likelihood estimates from the Barents Sea (Figure 8.1). The estimated probability of a large accidents during a single year for the pipelines with 1,000 km length is 10^{-4} , but experience from actual pipelines show an increases to 10^{-2} after long-term exploitation (Binenko, Berkovits, 2006).

8.2 Ship transport

Transport of oil and other petroleum products from ports and terminals in NW-Russia have been increasing steadily over the last decade (see Figure 8.2). In 2002, more than 4 million tons of Russian oil was exported along the Norwegian coast, in 2004, the volume reached almost 12 million and estimates show that in 2010, Russia may export of to 150 million of tons (Bambulyak, Frantsen, 2005). Every week in 2006 an average of 4 tankers (typically of ~ 50 000 tons tonnage) passed the Norwegian coast carrying crude oil to ports in Europe and USA. The shipping lanes are typically 12 – 30 nmi offshore, and in case accidents the vessels and cargo (oil) will be carried by the currents to the coast and along the coast into the Barents sea. Therefore, this risk of a major accident with such a tanker is one of the largest environmental risks posed to the Barents Sea ecosystem.

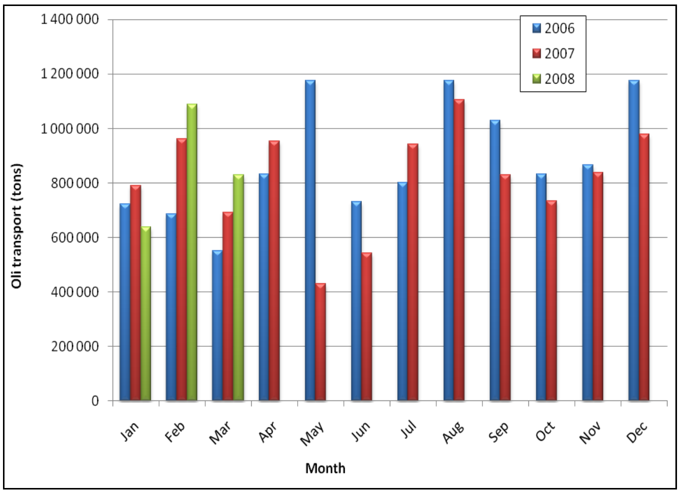

Figure 8.2. Amount of oil passing the Norwegian coast each month from oil-terminals in NW-Russia. Data from 2006 – 2007 is shown.

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

In Table 8.1 we have shown the estimated frequency of discharges from ship transport in the Barents Sea based on the limited data available on sailing under arctic conditions (Zhuravel, 2005).

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

Table 8.1. Estimates of frequency of oil discharge risk to the Barents Sea from shipping.

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

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

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

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

8.3 Introduced species

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

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

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

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

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

8.4 Human disturbances on bottom habitat

Based on the present knowledge, the absence of large attached hard-bottom megafauna (> 5 cm) organisms or communities might be the only benthic sign of physical disturbance from trawling or scraping. These communities are often connected to rocky bottoms at the edge of the continental shelf (corals) or in coastal areas (mussel beds). On the soft-bottom fields in the deeper parts of the Sea subjected to bottom trawling for prawn and cod, and in the shallower part with gravel and sand bottom, fragile species can be indicators of physical disturbance. This group includes e.g., sea anemones, soft corals, sponges, whelk eggs, bryozoans, ascidians, neptunid whelks, and empty shells that have been found to be more abundant in the unfished areas. The Barents Sea exploratory oil-drilling activities will introduce “physical disturbance” through the anchoring of platforms, the pipeline constructions and the deposition of cuttings. This disturbance might be detected by the destruction of fragile habitats or by decrease/elimination of long-lived vulnerable animals for an unknown period. Protecting areas for preventing the destruction of fragile habitats is important, although the ecological consequences for the Barents Sea proper might be obscure or impossible to detect.

8.5 Risk conclusions

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

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Sea surface temperature (SST) data: http://iridl.ldeo.columbia.edu

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

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

Documentation on the Bifrost model: http://www.assessment.imr.no

Documentation on the Gadget model: http://www.hafro.is/gadget

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11 Appendix 1

Fish species recorded in the Barents Sea based on literature and research survey data from IMR and PINRO. The zoogeographical groups are defined in section 2.4.5.1.

Order	**Family**	**Scientific name**	**Author**	**Zoo-geographical group**	**Comments**
Myxiniformes	Myxinidae	*Myxine glutinosa*	Linnaeus, 1758	B	
Petromyzontiformes	Petromyzontidae	*Lampetra fluviatilis*	(Linnaeus, 1758)		
Petromyzontiformes	Petromyzontidae	*Lethenteron camtschaticum*	(Tilesius, 1811)	MB	
Petromyzontiformes	Petromyzontidae	*Petromyzon marinus*	Linnaeus, 1758	SB	
Lamniformes	Lamnidae	*Lamna nasus*	(Bonnaterre, 1788)	SB	
Lamniformes	Cetorhinidae	*Cetorhinus maximus*	(Gunnerus, 1765)	WD	
Lamniformes	Alopiidae	*Alopias vulpinus*	(Bonnaterre, 1788)		Needs confirmation
Carcharhiniformes	Carcharhinidae	*Prionace glauca*	(Linnaeus, 1758)	WD	Needs confirmation
Carcharhiniformes	Scyliorhinidae	*Galeus melastomus*	Rafinesque, 1810	SB	Needs confirmation, known distribution N to about Tromsø
Carcharhiniformes	Scyliorhinidae	*Scyliorhinus canicula*	(Linnaeus, 1758)		Needs confirmation, rare north of Helgeland
Carcharhiniformes	Triakidae	*Galeorhinus galeus*	(Linnaeus, 1758)	WD	
Squaliformes	Dalatiidae	*Etmopterus spinax*	(Linnaeus, 1758)	WD	
Squaliformes	Dalatiidae	*Somniosus microcephalus*	(Bloch & Schneider 1801)	MB	
Squaliformes	Squalidae	*Squalus acanthias*	Linnaeus, 1758	WD	
Rajiformes	Rajidae	*Amblyraja hyperborea*	(Collett, 1879)	A	
Rajiformes	Rajidae	*Amblyraja radiata*	(Donovan, 1808)	MB	
Rajiformes	Rajidae	*Bathyraja spinicauda*	(Jensen, 1914)	MB	
Rajiformes	Rajidae	*Dipturus batis*	(Linnaeus, 1758)	B	
Rajiformes	Rajidae	*Dipturus linteus*	(Fries, 1838)	B	
Rajiformes	Rajidae	*Dipturus oxyrinchus*	(Linnaeus, 1758)	B	Needs confirmation, found north to Tromsø region
Rajiformes	Rajidae	*Leucoraja fullonica*	(Linnaeus, 1758)	B	
Rajiformes	Rajidae	*Raja clavata*	Linnaeus, 1758		Needs confirmation, found north to Tromsø region

Rajiformes	Rajidae	*Rajella fyllae*	(Lütken, 1888)	MB	
Chimaeriformes	Chimaeridae	*Chimaera monstrosa*	Linnaeus, 1758	B	
Notacanthiformes	Notacanthidae	*Notacanthus chemnitzii*	Bloch 1788	WD	Needs confirmation, rare NE of Shetland-Iceland
Anguilliformes	Anguillidae	*Anguilla anguilla*	(Linnaeus, 1758)	SB	
Anguilliformes	Congridae	*Conger conger*	(Linnaeus, 1758)		Needs confirmation, rare north of Trøndelag
Clupeiformes	Clupeidae	*Alosa alosa*	(Linnaeus, 1758)		Needs confirmation
Clupeiformes	Clupeidae	*Clupea harengus*	Linnaeus, 1758	MB	
Clupeiformes	Clupeidae	*Clupea pallasi marisalbi*	Berg, 1923	MB	
Clupeiformes	Clupeidae	*Clupea pallasii suworowi*	Rabinerson 1927		
Clupeiformes	Clupeidae	*Sprattus sprattus*	(Linnaeus, 1758)		Needs confirmation, rare as far north as Troms
Osmeriformes	Argentinidae	*Argentina silus*	(Ascanius, 1775)	B	
Osmeriformes	Argentinidae	*Argentina sphyraena*	Linnaeus, 1758		Needs confirmation, to be expected as vagrant
Osmeriformes	Microstomatidae	*Nansenia groenlandica*	(Reinhardt, 1840)	SB	
Osmeriformes	Osmeridae	*Mallotus villosus*	(Müller, 1776)	MB	
Osmeriformes	Osmeridae	*Osmerus eperlanus*	(Linnaeus, 1758)	B	
Salmoniformes	Salmonidae	*Oncorhynchus gorbusha*	(Walbaum, 1792)	MB	
Salmoniformes	Salmonidae	*Oncorhynchus keta*	(Walbaum, 1792)	MB	
Salmoniformes	Salmonidae	*Oncorhynchus mykiss*	(Walbaum, 1792)		Depending on limits of Barents Sea
Salmoniformes	Salmonidae	*Salmo salar*	Linnaeus, 1758	MB	
Salmoniformes	Salmonidae	*Salmo trutta*	Linnaeus, 1758	B	
Salmoniformes	Salmonidae	*Salvelinus alpinus*	(Linnaeus, 1758)	A	
Stomiiformes	Sternoptychidae	*Argyropelecus hemigymnus*	Cocco, 1829	WD	Needs confirmation, to be expected as vagrant
Stomiiformes	Sternoptychidae	*Argyropelecus olfersii*	(Cuvier, 1829)	WD	
Stomiiformes	Sternoptychidae	*Maurolicus muelleri*	(Gmelin, 1789)	B	
Stomiiformes	Stomiidae	*Chauliodus sloani*	Bloch & Schneider, 1801	WD	
Stomiiformes	Stomiidae	*Stomias boa ferox*	(Reinhardt, 1843)	B	Needs confirmation, very rare NE of Shetland-Iceland
Aulopiformes	Paralepididae	*Arctozenus risso*	(Bonaparte, 1840)	WD	
Aulopiformes	Paralepididae	*Paralepis coregonoides*	(Risso, 1820)	WD	Needs confirmation, rare NE of Shetl-Icel.; misidentified *A. risso*?
Myctophiformes	Myctophidae	*Benthosema glaciale*	(Reinhardt, 1837)	MB	

Myctophiformes	Myctophidae	*Lampanyctus crocodilus*	(Risso, 1810)	SB	
Myctophiformes	Myctophidae	*Lampanyctus macdonaldi*	(Goode & Bean, 1896)	WD	Needs confirmation, might be expected as vagrant?
Myctophiformes	Myctophidae	*Myctophum punctatum*	(Rafinesque, 1810)	SB	Needs confirmation, distribution N to Shetland-Iceland, and found Hordaland (W. Norway)
Myctophiformes	Myctophidae	*Protomyctophum arcticum*	(Lütken, 1892)	B	Needs confirmation, rare NE of Shetland-Iceland, but recorded Vesterålen
Myctophiformes	Myctophidae	*Notoscopelus kroyeri*	(Malm, 1861)	MB	Needs confirmation, distribution north to Shetland-Iceland
Gadiformes	Macrouridae	*Macrourus berglax*	Lacepede, 1801	B	
Gadiformes	Gadidae	*Arctogadus glacialis*	(Peters, 1874)	A	
Gadiformes	Gadidae	*Boreogadus saida*	(Lepechin, 1774)	A	
Gadiformes	Gadidae	*Eleginus nawaga*	(Koelreuter, 1770)	A	
Gadiformes	Gadidae	*Gadiculus argenteus thori*	Schmidt, 1914	SB	
Gadiformes	Gadidae	*Gadus morhua*	Linnaeus, 1758	MB	
Gadiformes	Gadidae	*Melanogrammus aeglefinus*	(Linnaeus, 1758)	MB	
Gadiformes	Gadidae	*Merlangius merlangus*	(Linnaeus, 1758)	SB	
Gadiformes	Gadidae	*Micromesistius poutassou*	(Risso, 1826)	MB	
Gadiformes	Gadidae	*Pollachius pollachius*	(Linnaeus, 1758)	B	
Gadiformes	Gadidae	*Pollachius virens*	(Linnaeus, 1758)	MB	
Gadiformes	Gadidae	*Raniceps raninus*	(Linnaeus, 1758)		Needs confirmation, northwards to Lofoten
Gadiformes	Gadidae	*Theragra finnmarchica*	Koefoed, 1956	B	
Gadiformes	Gadidae	*Trisopterus esmarkii*	(Nilsson, 1855)	B	
Gadiformes	Lotidae	*Brosme brosme*	(Ascanius, 1772)	MB	
Gadiformes	Lotidae	*Ciliata mustela*	(Linnaeus, 1758)	B	
Gadiformes	Lotidae	*Ciliata septentrionalis*	(Collett, 1875)	B	Needs confirmation, recorded north to Troms; probably very rare anywhere
Gadiformes	Lotidae	*Enchelyopus cimbrius*	(Linnaeus, 1766)	B	
Gadiformes	Lotidae	*Gaidropsarus argentatus*	(Reinhardt, 1838)	A	
Gadiformes	Lotidae	*Molva dypterygia*	(Pennant, 1784)	B	
Gadiformes	Lotidae	*Molva molva*	(Linnaeus, 1758)	B	
Gadiformes	Merlucciidae	*Merluccius merluccius*	(Linnaeus, 1758)	SB	Needs confirmation, rare north of Helgeland
Gadiformes	Phycidae	*Phycis blennoides*	(Brünnich, 1768)	SB	Needs confirmation, recorded north to Troms
Lophiiformes	Lophiidae	*Lophius piscatorius*	Linnaeus, 1758	SB	

Lophiiformes	Antennariidae	*Histrio histrio*	(Linnaeus, 1758)	WD	
Beloniformes	Scomberesocidae	*Scomberesox saurus*	Walbaum, 1792)	WD	
Beloniformes	Belonidae	*Belone belone*	(Linnaeus, 1761)	B	
Lampriformes	Lamprididae	*Lampris guttatus*	(Brünnich, 1788)	WD	
Lampriformes	Trachipteridae	*Trachipterus arcticus*	(Brünnich, 1771)	WD	
Lampriformes	Regalecidae	*Regalecus glesne*	Ascanius, 1772	WD	
Beryciformes	Berycidae	*Beryx decadactylus*	Cuvier, 1829	WD	
Gasterosteiformes	Gasterosteidae	*Gasterosteus aculeatus*	Linnaeus, 1758	MB	
Gasterosteiformes	Gasterosteidae	*Pungitius pungitius*	(Linnaeus, 1758)		
Gasterosteiformes	Gasterosteidae	*Spinachia spinachia*	(Linnaeus, 1758)	B	Needs confirmation, rare N of Troms
Syngnathiformes	Syngnathidae	*Entelurus aequoreus*	(Linnaeus, 1758)	B	
Syngnathiformes	Syngnathidae	*Nerophis lumbriciformis*	(Jenyns, 1835)		Needs confirmation, rare N of Trøndelag
Syngnathiformes	Syngnathidae	*Syngnathus typhle*	Linnaeus, 1758	B	
Scorpaeniformes	Scorpaenidae	*Helicolenus dactylopterus*	(Delaroche, 1809)	SB	
Scorpaeniformes	Sebastidae	*Sebastes marinus*	(Linnaeus, 1758)	MB	
Scorpaeniformes	Sebastidae	*Sebastes mentella*	Travin 1951	MB	
Scorpaeniformes	Sebastidae	*Sebastes viviparus*	Kröyer, 1844	B	
Scorpaeniformes	Triglidae	*Chelidonichthys lucernus*	(Linnaeus, 1758)		Needs confirmation, known north to Tromsø, might be expected in Barents Sea
Scorpaeniformes	Triglidae	*Eutrigla gurnardus*	(Linnaeus, 1758)	SB	
Scorpaeniformes	Cottidae	*Artediellus atlanticus*	Jordan & Evermann, 1898	MB	
Scorpaeniformes	Cottidae	*Artediellus scaber*	Knipowitsch, 1907	A	
Scorpaeniformes	Cottidae	*Gymnocanthus tricuspis*	(Reinhardt, 1830)	MA	
Scorpaeniformes	Cottidae	*Icelus bicornis*	(Reinhardt, 1840)	MA	
Scorpaeniformes	Cottidae	*Icelus spatula*	Gilbert & Burke, 1912	AB	
Scorpaeniformes	Cottidae	*Myoxocephalus quadricornis*	(Linnaeus, 1758)	A	
Scorpaeniformes	Cottidae	*Myoxocephalus scorpius*	(Linnaeus, 1758)	MB	
Scorpaeniformes	Cottidae	*Taurulus bubalis*	(Euphrasen, 1786)	B	
Scorpaeniformes	Cottidae	*Triglops murrayi*	Günther, 1888	B	
Scorpaeniformes	Cottidae	*Triglops nybelini*	Jensen, 1944	A	

Scorpaeniformes	Cottidae	*Triglops pingelii*	Reinhardt, 1937	AB	
Scorpaeniformes	Psychrolutidae	*Cottunculus microps*	Collett, 1875	MA	
Scorpaeniformes	Psychrolutidae	*Cottunculus sadko*	Essipov, 1937	A	
Scorpaeniformes	Agonidae	*Agonus cataphractus*	Linnaeus, 1758)	B	
Scorpaeniformes	Agonidae	*Leptagonus decagonus*	(Bloch & Schneider, 1801)	AB	
Scorpaeniformes	Agonidae	*Ulcina olrikii*	(Lütken, 1876)	A	
Scorpaeniformes	Cyclopteridae	*Cyclopteropsis macalpini*	(Fowler, 1914)	A	
Scorpaeniformes	Cyclopteridae	*Cyclopterus lumpus*	Linnaeus, 1758	MB	
Scorpaeniformes	Cyclopteridae	*Eumicrotremus derjugini*	Popov, 1926	A	
Scorpaeniformes	Cyclopteridae	*Eumicrotremus spinosus*	(Fabricius, 1776)	MA	
Scorpaeniformes	Liparidae	*Careproctus derjugini*	Chernova, 2005		following recent revision (Chernova 2005)
Scorpaeniformes	Liparidae	*Careproctus dubius*	Zugmayer, 1911	A	following recent revision (Chernova 2005)
Scorpaeniformes	Liparidae	*Careproctus knipowitschi*	Chernova, 2005		following recent revision (Chernova 2005)
Scorpaeniformes	Liparidae	*Careproctus macrophthalmus*	Chernova, 2005		following recent revision (Chernova 2005)
Scorpaeniformes	Liparidae	*Careproctus tapirus*	Chernova, 2005		following recent revision (Chernova 2005)
Scorpaeniformes	Liparidae	*Careproctus telescopus*	Chernova, 2005		following recent revision (Chernova 2005)
Scorpaeniformes	Liparidae	*Liparis fabricii*	Kröyer, 1847	A	
Scorpaeniformes	Liparidae	*Liparis gibbus*	Bean, 1881	MA	
Scorpaeniformes	Liparidae	*Liparis liparis*	(Linnaeus, 1766)	B	
Scorpaeniformes	Liparidae	*Liparis montagui*	(Donovan, 1805)	B	
Scorpaeniformes	Liparidae	*Liparis tunicatus*	Reinhardt, 1837	A	
Scorpaeniformes	Liparidae	*Paraliparis bathybius*	(Collett, 1879)	A	
Scorpaeniformes	Liparidae	*Rhodichthys regina*	Collett, 1879	A	Depending on limits of Barents Sea,
Perciformes	Moronidae	*Dicentrarchus labrax*	(Linnaeus, 1758)	SB	
Perciformes	Polyprionidae	*Polyprion americanus*	(Bloch & Schneider, 1801)		
Perciformes	Carangidae	*Trachurus trachurus*	(Linnaeus, 1758)		Needs confirmation, recorded N to Troms, but can be expected
Perciformes	Bramidae	*Brama brama*	(Bonnaterre, 1788)	WD	

Perciformes	Bramidae	*Pterycombus brama*	Fries, 1837	SB	
Perciformes	Bramidae	*Taractes asper*	Lowe 1983	WD	Needs confirmation, very rare NE of Faroes-Iceland
Perciformes	Sparidae	*Pagellus bogaraveo*	(Brünnich, 1768)		Needs confirmation, recorded northward to Tromsø; expected vagrant in BS
Perciformes	Sparidae	*Spondyliosoma cantharus*	(Linnaeus, 1758)		Needs confirmation, very rare N of Trondheimsfjorden
Perciformes	Mugilidae	*Chelon labrosus*	(Risso, 1826)		
Perciformes	Zoarcidae	*Gymnelus andersoni*	Chernova, 1998		
Perciformes	Zoarcidae	*Gymnelus esipovi*	Chernova, 1999		Needs confirmation, known from the Arctic Ocean (Chernova 1999)
Perciformes	Zoarcidae	*Gymnelus retrodorsalis*	Le Danois, 1913	A	
Perciformes	Zoarcidae	*Gymnelus taeniatus*	Chernova, 1999		Depending on limits of Barents Sea, known from near Franz Josef Land (Chernova 1999)
Perciformes	Zoarcidae	*Gymnelus viridis*	(Fabricius, 1780)	A	Needs confirmation, found along E Greenland
Perciformes	Zoarcidae	*Lycenchelys kolthoffi*	Jensen 1903	A	
Perciformes	Zoarcidae	*Lycenchelys muraena*	(Collett, 1878)	A	
Perciformes	Zoarcidae	*Lycenchelys platyrhina*	(Jensen, 1901)	A	Needs confirmation
Perciformes	Zoarcidae	*Lycenchelys sarsii*	(Collett, 1871)	B	
Perciformes	Zoarcidae	*Lycodes adolfi*	Nielsen and Fosså, 1993	A	
Perciformes	Zoarcidae	*Lycodes esmarkii*	Collett, 1875	MB	
Perciformes	Zoarcidae	*Lycodes eudipleurostictus*	Jensen, 1901	A	
Perciformes	Zoarcidae	*Lycodes frigidus*	Collett, 1878	A	
Perciformes	Zoarcidae	*Lycodes gracilis*	Sars, 1867	MB	
Perciformes	Zoarcidae	*Lycodes jugoricus*	Knipowitch, 1906	A	
Perciformes	Zoarcidae	*Lycodes luetkeni*	Collett 1880	A	
Perciformes	Zoarcidae	*Lycodes pallidus*	Collett, 1878	A	
Perciformes	Zoarcidae	*Lycodes polaris*	(Sabine, 1824)	A	
Perciformes	Zoarcidae	*Lycodes reticulatus*	Reinhardt, 1935	A	
Perciformes	Zoarcidae	*Lycodes rossi*	Malmgren, 1864	A	
Perciformes	Zoarcidae	*Lycodes seminudus*	Reinhardt, 1837	A	
Perciformes	Zoarcidae	*Lycodes squamiventer*	Jensen, 1904	A	
Perciformes	Zoarcidae	*Lycodonus flagellicauda*	(Jensen, 1901)	A	

Perciformes	Zoarcidae	*Zoarces viviparus*	(Linnaeus, 1758)	MB	
Perciformes	Stichaeidae	*Anisarchus medius*	(Reinhardt, 1837)	B	
Perciformes	Stichaeidae	*Chirolophis ascanii*	(Walbaum, 1792)	B	
Perciformes	Stichaeidae	*Leptoclinus maculatus*	(Fries, 1838)	MB	
Perciformes	Stichaeidae	*Lumpenus fabricii*	Reinhardt, 1836	MA	
Perciformes	Stichaeidae	*Lumpenus lampretaeformis*	(Walbaum, 1792)	MB	
Perciformes	Pholidae	*Pholis gunnellus*	(Linnaeus, 1758)	MB	
Perciformes	Anarhichadidae	*Anarhichas denticulatus*	Kröyer, 1845	MB	
Perciformes	Anarhichadidae	*Anarhichas lupus*	Linnaeus, 1758	MB	
Perciformes	Anarhichadidae	*Anarhichas minor*	Olafsen, 1772	MB	
Perciformes	Ammodytidae	*Ammodytes marinus*	Raitt, 1934	MB	
Perciformes	Ammodytidae	*Hyperoplus lanceolatus*	(Sauvage, 1824)	B	
Perciformes	Gobiidae	*Crystallogobius linearis*	(Düben, 1845)		Needs confirmation, rare north of Trondheimsfjorden
Perciformes	Gobiidae	*Gobiosculus flavescens*	(Fabricius, 1779)		Needs confirmation, recorded N to about Andøya
Perciformes	Gobiidae	*Pomatoschistus minutus*	(Pallas, 1770)		Needs confirmation, recorded north to Troms
Perciformes	Gobiidae	*Pomatoschistus norvegicus*	Collett, 1902)		Needs confirmation, recorded north to Vestfjorden
Perciformes	Gempylidae	*Nesiarchus nasutus*	Johnson, 1862		
Perciformes	Trichiuridae	*Aphanopus carbo*	Lowe 1983	B	Needs confirmation, might be expected as vagrant
Perciformes	Trichiuridae	*Benthodesmus elongatus*	(Clarke, 1879)		rarely found NE of Shetland-Iceland
Perciformes	Xiphiidae	*Xiphias gladius*	Linnaeus, 1758	WD	
Perciformes	Scombridae	*Scomber scombrus*	Linnaeus, 1758	SB	
Perciformes	Scombridae	*Thunnus thynnus*	(Linnaeus, 1758)	WD	
Perciformes	Callionymidae	*Callionymus lyra*	Linnaeus, 1758		Needs confirmation, not documented N of Lofoten
Perciformes	Centrolophidae	*Centrolophus niger*	(Gmelin, 1788)	WD	
Perciformes	Centrolophidae	*Schedophilus medusophagus*	(Cocco, 1839)		
Pleuronectiformes	Pleuronectidae	*Glyptocephalus cynoglossus*	(Linnaeus, 1758)	MB	
Pleuronectiformes	Pleuronectidae	*Hippoglossoides platessoides*	(Fabricius, 1780)	MB	
Pleuronectiformes	Pleuronectidae	*Hippoglossus hippoglossus*	(Linnaeus, 1758)	MB	
Pleuronectiformes	Pleuronectidae	*Limanda limanda*	(Linnaeus, 1758)	MB	

Pleuronectiformes	Pleuronectidae	*Microstomus kitt*	(Walbaum, 1792)	B	
Pleuronectiformes	Pleuronectidae	*Platichthys flesus*	(Linnaeus, 1758)	MB	
Pleuronectiformes	Pleuronectidae	*Pleuronectes glacialis*	(Pallas, 1776)		
Pleuronectiformes	Pleuronectidae	*Pleuronectes platessa*	Linnaeus, 1758	MB	
Pleuronectiformes	Pleuronectidae	*Reinhardtius hippoglossoides*	(Walbaum, 1792)	MA	
Pleuronectiformes	Scophthalmidae	*Lepidorhombus whiffiagonis*	(Walbaum, 1792)		
Pleuronectiformes	Scophthalmidae	*Psetta maxima*	(Linnaeus, 1758)	B	
Pleuronectiformes	Scophthalmidae	*Scophthalmus rhombus*	(Linnaeus, 1758)		Needs confirmation, rare north of Trøndelag
Pleuronectiformes	Scophthalmidae	*Zeugopterus norvegicus*	(Günther, 1862)	B	
Tetraodontiformes	Molidae	*Mola mola*	(Linnaeus, 1758)	WD	

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JOINT REPORT

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