3 THE BARENTS SEA AND THE NORWEGIAN SEA

3.1 Ecosystem Overview

3.1.1 Ecosystem components

General geography

The Barents Sea is a shelf area of approx. 1.4 million km^2, which borders to the Norwegian Sea in the west and the Arctic Ocean in the north, and is part of the continental shelf area surrounding the Arctic Ocean. The extent of the Barents Sea are limited by the continental slope between Norway and Spitsbergen in west, the continental slope towards the Arctic Ocean in north, Novaya Zemlya in east and the coast of Norway and Russia in the south (Figure 3.1.1). The average depth is 230 m, with a maximum depth of about 500 m at the western entrance. There are several bank areas, with depths between 50–200 m.

General oceanography

The general circulation pattern in the Barents Sea is strongly influenced by topography. Warm Atlantic waters from the Norwegian Atlantic Current defined by salinity higher than 35 flows in through the western entrance. This current divides into two branches, one southern branch, which follows the coast eastwards against Novaya Zemlya and one northern branch, which flow into the Hopen Trench. The relative strength of these two branches depends on the local wind conditions in the Barents Sea. South of the Norwegian Atlantic Current and along the coastline flows the Norwegian Coastal Current. The Coastal Water is fresher than the Atlantic water, and has a stronger seasonal temperature signal. In the northern part of the Barents Sea fresh and cold Arctic water flows from northeast to southwest. The Atlantic and Arctic water masses are separated by the Polar Front, which is characterized by strong gradients in both temperature and salinity. In the western Barents Sea the position of the front is relatively stable, although it seems to be pushed northwards during warm climatic periods. In the eastern part the position of the front has large seasonal, as well as year- to-year variations. Ice conditions show also large seasonal and year-to year variations. In the winter the ice can cover most of the northern Barents Sea, while in the summer the whole Sea may be ice-free. In general, the Barents Sea is characterized by large year-to-year variations in both heat content and ice conditions. The most important cause of this is variation in the amount and temperature of the Atlantic water that enters the Barents Sea.

The water temperatures in the Barents Sea have been relatively high during most of the 1990s, with a continuous warm period from 1989–1995. During 1996–1997, the temperature was just below the long-term average before it turned warm again and showed a pronounced warming toward present. During the last 10 years the mean temperature has increased with more than 1^{o}C, the annual mean volume flux of Atlantic Water inflow has nearly doubled and the warm water has spread eastwards. 2006 was the warmest year ever recorded (Figure 3.1.2).

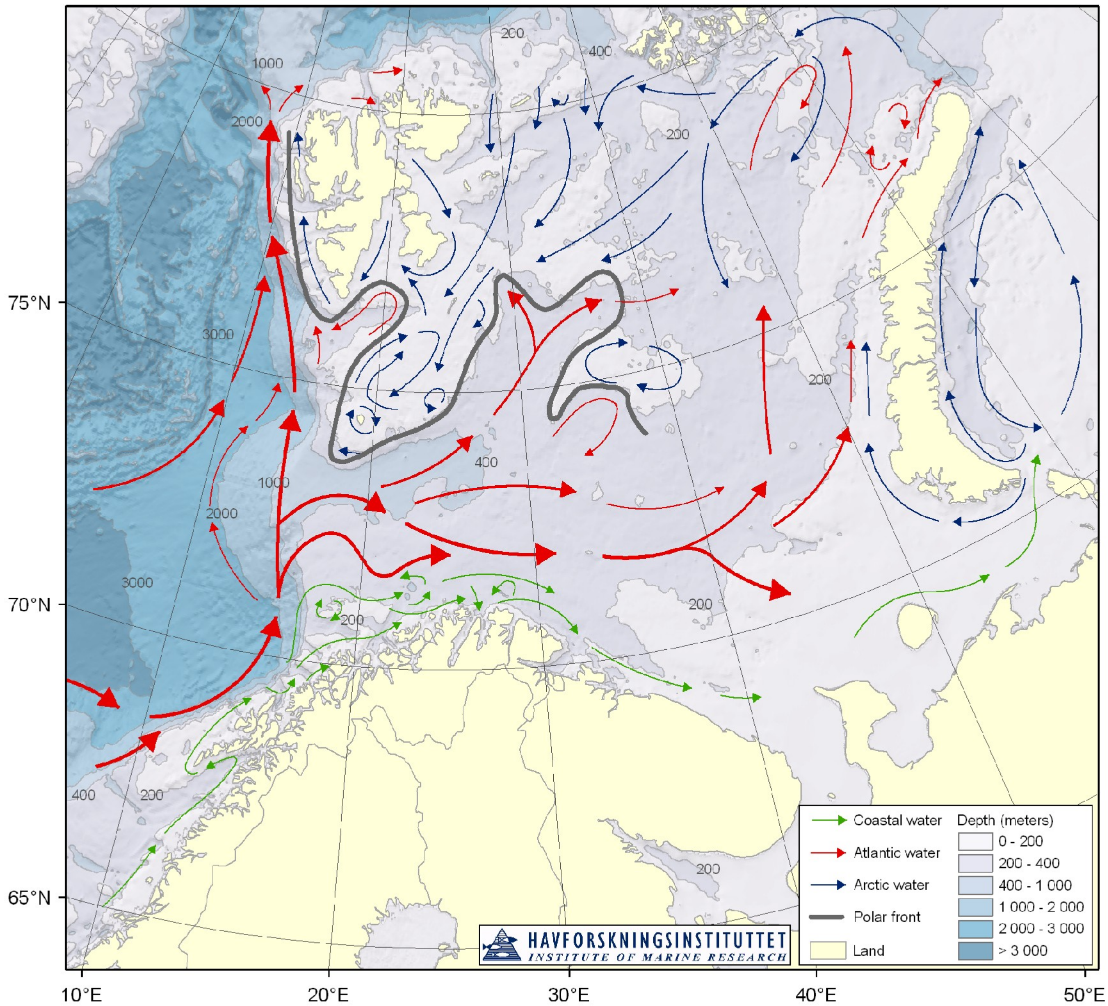

Figure 3.1.1 Bottom contours and current systems in the Barents Sea.

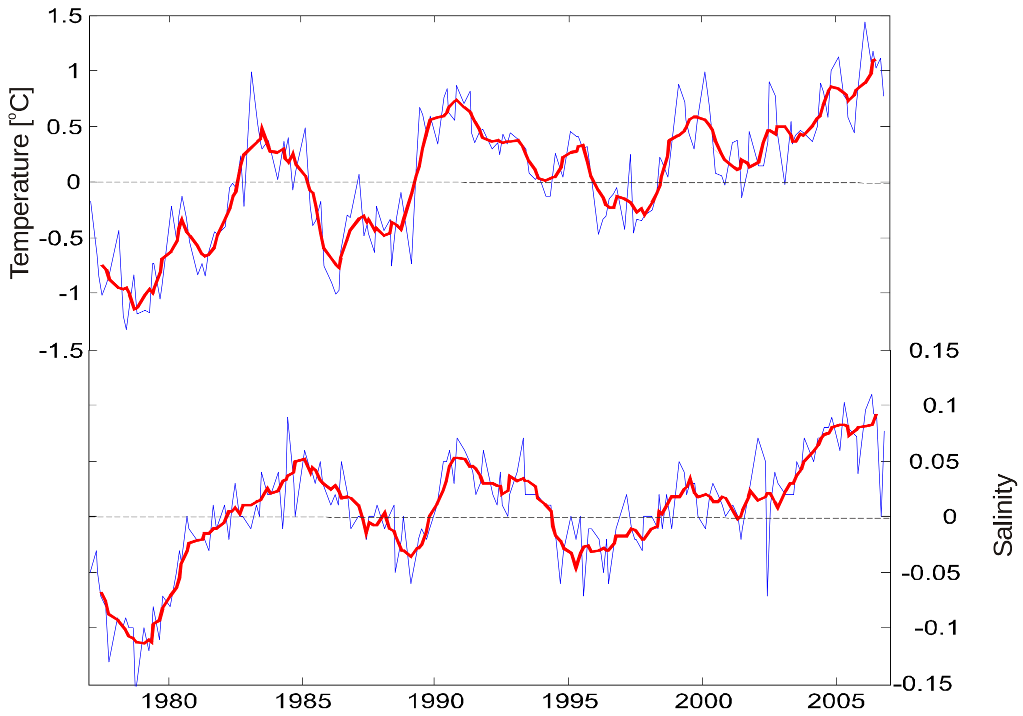

Figure 3.1.2 Temperature (upper graph) and salinity (lower graph) anomalies in the Fugløya-Bjørnøya transect during the period 1977–2006.

Phytoplankton

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

Zooplankton

Zooplankton biomass has shown large variation among years in the Barents Sea. Crustaceans form the most important group of zooplankton, among which the copepods of the genus Calanus play a key role in the Barents Sea ecosystem. *Calanus finmarchicus*, which is the most abundant in the Atlantic waters, is the main contributor to the zooplankton biomass. *Calanus glacialis* is the dominant contributor to zooplankton biomass of the Arctic region of the Barents Sea. The Calanus species are predominantly herbivorous, feeding especially on diatoms (Mauchlin, 1998). Krill (euphausiids) is another group of crustaceans playing a significant role in the Barents Sea ecosystem as food for both fish and sea mammals. The Barents Sea community of euphausiids is represented by four abundant species: neritic shelf boreal *Meganyctiphanes norvegica*, oceanic arcto-boreal *Thysanoessa longicaudata*, neritic shelf arcto-boreal *Th. inermis* and neritic coastal arcto-boreal *Th. raschii* (Drobysheva, 1994). The two latter species make up 80-98% of the total euphausiids abundance. Species ratio in the Barents Sea euphausiid community is characterized by year-to-year variability, most probably due to climatic changes (Drobysheva, 1994). The observations showed that after cooling the abundance of *Th. raschii* increases and of *Th. inermis* decreases, while after the number of warm years, on the contrary, the abundance of *Th. inermis* grows and the number of cold-water species becomes smaller (Drobysheva, 1967). The advection of species brought from the Norwegian Sea is determined by the intensity of the Atlantic water inflow (Drobysheva, 1967, Drobysheva *et al*., 2003). Three abundant amphipod species are found in the Barents Sea; *Themisto abyssorum* and *T. libellula* are common in the western and central Barents Sea, while *T. compressa* is less common in the central and northern parts of the Barents Sea. *T. abyssorum* is predominant in the sub-arctic waters. In contrast, the largest of the Themisto species, *T. libellula*, is mainly restricted to the mixed Atlantic and Arctic water masses. A very high abundance of *T. libellula* is recorded close to the Polar Front.

Benthic habitats

Barents Sea

Benthic organisms (benthos) in the Barents Sea are found on or buried in the seabed, but their composition is highly dependent on the predominating type of water (Arctic or Atlantic water, or at their convergence), the bottom substrate and the depth. The richest communities of benthic animals are found along the Norwegian coast and the coast of Svalbard, where the hard-bottom communities display an unusually high richness of species. Among these, kelp is a key species along the Norwegian coast, whereas other species of seaweeds dominate in Svalbard. The kelp forests are extremely valuable biotopes and home to a large number of invertebrates and fish that spawn and grow up here. Sea urchins, *Strongylocentrotus droebachiensis*, are attached to this biotope and graze on the kelp stalks. Another example of a biotope containing a particularly large number of species is the deep-water coral reefs, especially those with the stone coral, *Lophelia pertusa*. Reefs are known to be on the shelf off Finnmark. Just as the coral reefs offer space for an associated abundance of animal life, the occurrences of sponges in the Barents Sea are valuable for the species diversity. Large aggregations of sponges (for example *Geodia*) have been found on Tromsøflaket, and these are currently being mapped. The deeper parts of the Barents Sea are covered by fine-grained sediment, sand and mud, and the infauna (benthic animals living in the sediment) are dominated by polychaetes (bristleworms). The echinoderms, brittle stars and sea urchins, are important constituents of the bottom fauna. On the shallower banks, the sediment is coarser due to current activity, and there are larger numbers of bivalves here, such as the Iceland scallop, *Chlamys islandica*. This species has been fished quite extensively.

A relationship has been found between the biomass of benthic animals and the ice edge in the Barents Sea. This increase in the biomass is correlated, among other things, with the high seasonal pulse in the growth of algae during the short, intense spring, and with processes in the water that cause the food to sink to the bottom. However, as the ice margin may vary by several hundred kilometres from year to year, the benthic animals must also tolerate large fluctuations in the accessibility of food.

Red king crab (*Paralithodes camtschatica*) was introduced to the Barents Sea in the 1960s (Jørgensen and Hop). The stock is growing and expanding eastwards and along the Norwegian coast westwards. Adult red king crabs are opportunistic omnivores.

Northern shrimp (*Pandalus borealis)* is an important prey for several fish species, especially cod, but also other fish stocks like blue whiting (ICES, 2005). Consumption by cod significantly influences shrimp population dynamics. The estimated amount of shrimp consumed by cod is on average much higher than shrimp landings. Shrimp is most abundant in central parts of the Barents Sea and close to Svalbard, mostly on 200–350 meter depths (Aschan, 2000). It is common close to the sea floor, preferably silt or fine-grained sand. Shrimp in the southern parts of the Barents Sea grow and mature faster than shrimp in the central or northern parts.

Fish communities

Barents Sea

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

Capelin (*Mallotus villosus*) plays a major role in the Barents Sea ecology, even though the stock has fluctuated greatly in recent years. In summer, they migrate northwards and feed on the zooplankton as the ice margin retreats. Here, they have continuous access to new food resources in the productive zone that has just become ice-free. In September-October, the capelin may have reached 80ºN before they migrate southwards again to spawn on the coasts of north Norway and Russia. In the central and southern Barents Sea, the capelin become prey for cod. Some marine mammals and seabirds also have a strong preference for capelin. Their feeding migration means that capelin function as transporters of biomass from the ice margin to the Norwegian coast, and that the production from areas covered by ice in winter is available for the cod. The capelin were heavily fished in the 1970s and the first half of the 1980s at a time when there were few herring in the area. In the mid-1980s, the stock collapsed and has since varied greatly. Fishing is permitted when the stock is both strong enough for good recruitment and to cover the consumption by cod.

Polar cod (*Boreogadus saida*) are adapted to cold water and live mainly in the eastern and northern Barents Sea. They are an important prey for many marine mammals and seabirds, but have little commercial significance.

Cod (*Gadus morhua*) are the most important predator fish in the Barents Sea and take a variety of prey. They spawn along the Norwegian coast from Møre to Finnmark, and after hatching they are dependent on *Calanus finmarchicus nauplii* in the initial phase of their growth before they begin to take larger plankton and small fish. In addition to capelin, shrimps and amphipods are important prey.

Haddock (*Melanogrammus aeglefinus*) feed on somewhat smaller prey, especially among the benthic fauna. The stock has substantial natural fluctuations, but is currently strong.

Saithe (*Pollachius virens*) are the third large member of the cod family with substantial economic importance, and occurs in comparatively warm, coastal waters. Like cod, saithe fry depend upon zooplankton, but saithe subsequently become important predators on other fish.

Blue whiting (*Micromesistius poutassou*) are a smaller member of the cod family, and has its main distribution in the southern part of the northeast Atlantic. It mostly eats plankton, but larger individuals also take small fish. It can enter the southern Barents Sea in warm years.

Norwegian spring-spawning herring (*Clupea harengus*) spawn along the Norwegian coast from Lindesnes in the south to Vesterålen, grow up in the Barents Sea and feed in the Norwegian Sea as adults. In years when recruitment is good, most of the 0-group individuals drift passively into the Barents Sea, where they remain until they are around three years old. The young herring are predators on capelin larvae, and when there are many herring in the Barents Sea the capelin recruitment and the capelin stock will be depleted. This has great consequences for the balance between the species of fish in the area and for the ecosystem in general. A depleted capelin stock means less transport of production from the northern to the southern Barents Sea, and less supply of capelin for cod and other predators. It appears as though herring only to a limited extent replace capelin as prey for cod; hence, there will also be less production of species that depend upon capelin. Young herring are not fished in the Barents Sea, but some catches of adult herring are taken in the southwestern part of the management area.

Deep-water redfish (*Sebastes mentella*) and golden redfish (*Sebastes marinus*) are slow-growing, deep-water species that have been heavily fished, and their fishing is now strictly regulated to rebuild the stocks. Redfish fry eat plankton, whereas larger individuals take larger prey, including fish.

Greenland halibut (*Reinhardtius hippoglossoides*) have an extensive distribution in deep water along the continental slope between the Barents Sea and the Norwegian Sea. It is also found in the deeper parts of the Barents Sea and north of Spitsbergen. Juveniles live in the northern parts of the Barents Sea. Fish, squids, octopi and crustaceans are the most important food of the Greenland halibut. The Greenland halibut stock is depleted at present, and fishing is strictly regulated.

Seabirds

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

There are about 1 750 000 breeding pairs of Brünnich's guillemot (*Uria lomvia*) in the Barents region. They live on fish, particularly polar cod, and ice fauna.

The population of common guillemots (*Uria aalge*) is about 140 000 breeding pairs. Capelin is the most important food source all the year round.

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

The black-legged kittiwake (*Rissa tridactyla*) breeds around the whole of Svalbard, but like the Brünnich's guillemot it is most common on Bjørnøya, Hopen and around Storfjorden. Its most important food items in the Barents Sea are capelin, polar cod and crustaceans. The breeding population seems stable, comprising 850 000 pairs in the Barents region.

The northern fulmar (*Fulmarus glacialis*) is an abundant Arctic and sub-Arctic species living far out to sea except in the breeding season. It lives on plankton and small fish taken from the surface. The population estimates are uncertain, but high (100 000–1 000 000 pairs).

The Atlantic puffin (*Fratercula arctica*) is the most abundant seabird on the mainland and in the Norwegian Sea, but may also breed on Bjørnøya and on Svalbard.

Marine mammals

Barents Sea

About 24 species of marine mammals regularly occur in the Barents Sea, comprising seven pinnipeds (seals), twelve large cetaceans (large whales) and five small cetaceans (porpoises and dolphins). Some of these species (including all the baleen whales) have temperate/tropical mating and calving areas and feeding areas in the Barents Sea (*e.g.* minke whale *Balaenoptera acutorostrata*), others reside in the Barents Sea all year round (*e.g.* white-beaked dolphin *Lagenorhynchus albirostris* and harbour porpoise *Phocoena phocoena*). Only the beluga whale (*Delphinapterus leucas*), the bowhead whale (*Balaena mysticetus*) and the narwhal (*Monodon monoceros*) remain in the area throughout the year.

The currently available abundance estimates of the most abundant cetaceans in the north-east Atlantic (*i.e.* comprising the North, Norwegian, Greenland and Barents Seas) are: minke whales 107 205; fin whales *B. physalus* 5400; humpback whales *Megaptera novaeangliae* 1200; sperm whales *Physeter macrocephalus* 4300 (Skaug *et al.*, 2002, Øien 2003, Skaug *et al.*, 2004).

Lagenorhyncus dolphins are the most numerous smaller cetaceans, with an abundance of 130 000 individuals (Øien, 1996). The population of harbour porpoises (*Phocoena phocoena*) has been estimated to 11 000 (Bjørge and Øien, 1995) in the Barents Sea, mostly along the coast.

Beluga whales may occur in groups varying from a few individuals to more than 1000. It is one of the most commonly observed whales off Svalbard. It may feed on everything from benthic invertebrates, octopi and squids to fish.

The bowhead whale is an arctic species closely attached to the sea ice, but is rarely observed in the Barents Sea. No estimates of the Barents Sea population exist but it is agreed that it is small, maybe in the tens. Before it was decimated by whaling, the bowhead whale was very numerous in the fjords and along the coast of Spitsbergen. It feeds on various species of zooplankton.

The killer whale also enters the Barents Sea, but its life cycle presently is tightly connected to the migrations of the Norwegian spring spawning herring.

Harp seals are the most numerous seal in the Barents Sea with approximately 2.2 million individuals. The Norwegian coast has experienced periodical invasions of harp seals.

Ringed seals are abundant in the Svalbard area and the ice-covered parts of the Barents Sea. They mostly live solitarily and take polar cod, shrimps and amphipods beneath the ice.

The bearded seal is another common, solitary species. It lives in the ice-covered parts of the Barents Sea and the fjords around Svalbard taking benthic organisms like shells, crabs and shrimps, which it finds in shallow water.

The harbour seal mainly lives in colonies along the Norwegian coast and in other coastal areas. In 1994–1998, close to 1300 individuals were recorded along the Norwegian coast. In addition, there is a small population off Svalbard.

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

Knowledge gaps

Inflow of water from the Norwegian Sea to the Barents Sea brings with it populations of phyto- and zoo-plankton which become part of the Barents Sea production system. A study of the volume and timing of inflow events and plankton production in the Barents Sea would be helpful in understanding this part of the production system.

Gjøsæter *et al.* (2002) showed that there is a connection between measured zooplankton biomass and capelin growth during the following year. Further work on the connection between zooplankton production and the production of pelagic forage fishes (capelin, polar cod, herring and possibly blue whiting) would be important in understanding the mechanisms of food supply for cod and larger predators like harp seals and minke whales.

Data about stomach contents and prey consumption for cod is available for a number of years and is used by AFWG. Information about predator/prey relationships is needed for more of the quantitatively important consumer species and groups.

Fisheries statistics from the Barents Sea does not fully reflect landings and discards, as has been described for cod in AFWG reports.

More information on these points would improve the qualitative and quantitative understanding of the production system being harvested through fishing, and the effects of fishing on the ecosystem.

3.2 Human impacts on the ecosystem

3.2.1 Fisheries effects on benthos and fish communities

Barents Sea

In order to conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. However, its qualitative effects have been studied to some degree (ICES, 2000). The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. In sandy bottoms of high seas fishing grounds trawling disturbances have not produced large changes in the benthic assemblages, as these habitats may be resistant to trawling due to natural disturbances and large natural variability. Studies on impacts of shrimp trawling on clay-silt bottoms have not demonstrated clear and consistent effects, but potential changes may be masked by the more pronounced temporal variability in these habitats (Løkkeborg, 2004). 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 catching 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 nets, and mortality caused by contact with active fishing gear such as escape mortality. Some small-scale effects are demonstrated, but the population effect is not known. The harbour porpoise (Phocoena phocoena) 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 bycatches in gillnet fisheries (Bjørge and Kovacs, 2005). In 2004 Norway initiated a monitoring program on bycatches 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 bycatch, but also increases fish catch, as bait loss is reduced. This way there is an economic incentive for the fishermen, and where bird bycatch is a problem, the bird scaring line is used without any forced regulation.

Fishing on capelin has the potential to disrupt the food chain between zooplankton and predators like cod, harp seals, minke whales and some birds. However, fishing on capelin is only permitted when the stock is sufficiently large enough both to sustain the predation by cod and to allow good recruitment.

Estimates on unreported catches on cod and haddock the last years indicate that this is a considerable problem; around 20% in addition to official catches in the period 2001–2005 (ICES, 2006).

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3.2.3 The Norwegian Sea

Ecosystem components

General geography

The Norwegian Sea is traditionally defined as the ocean bounded by a line drawn from the Norwegian Coast at about 62°N to Shetland, further to the Faroes-East Iceland-Jan Mayen-the southern tip of Spitsbergen-the Vesterålen at the Norwegian coast and the along the coast. In addition a wedge shaped strip along the western coast of Spitsbergen is included. The offshore boundaries follow in large part the mid Atlantic subsurface ridges.

The Norwegian Sea has an area of 1.1 million km^2 and a volume of more than 2 million km^3, i.e. an average depth of about 2000 m. The Norwegian Sea is divided into two separate basins with 3000 m to 4000 m depth, with maximum depth 4020 m. Along the Norwegian coast there is a relatively narrow continental shelf, between 40 and 200 km wide and with varied topography and geology. It has a relatively level sea bottom with depths between 100 and 400 m. The shelf is crossed by several troughs deeper than 300. Moraine deposits dominate the bottom substratum on the shelf, but soft layered clay is commonly found in the deeper parts. Gravelly and sandy bottoms are found near the shelf break and on ridges where the currents are strong and the sedimentation rates low.

General oceanography

The circulation in the Norwegian Sea (Figure 3.2.3.1) is strongly affected by the topography. On the continental shelf at the eastern margin of the area flows the low salinity Norwegian Coastal Current. It enters the area from the North Sea in the south and exits to the Barents Sea in the north east. The inflow of water from the north Atlantic to the Norwegian Sea takes place through the Faroe-Shetland Channel and flow over the Iceland-Faroe Ridge. At the northern slope of the ridge the warm Atlantic water meets the cold Arctic water and the boundary between these waters are called the Iceland Faroe Front. The major part of the warm and high salinity Atlantic Water continues northward as the Norwegian Atlantic Current along the Norwegian shelf, but parts of it branches into the North Sea and also to the more central parts of the Norwegian Sea. At the western boundary of the Barents Sea, the Norwegian Atlantic Current further bifurcates into the North Cape Current flowing eastwards into the Barents Sea and the West Spitsbergen Current flowing northwards into the Fram Strait (Furevik 2001).

The border zones between the domains of the Norwegian Atlantic Current and the Arctic waters to the west are known as the Arctic and Jan Mayen Fronts, located north and south of Jan Mayen, respectively. Cold and low salinity Arctic Water flows into the southern Norwegian Sea in the East Icelandic Current. At the northern flank of the Iceland Faroe Ridge the East Icelandic Current meets the warm Atlantic Water that crosses the ridge into the Norwegian Sea and this boundary is called the Iceland Faroe Front. The front has a clear surface signature, but a part of the Arctic Water submerges under the Atlantic Water and thus becomes Arctic Intermediate Water.

With respect to the underlying waters, there is evidence that the Arctic Intermediate Water has been expanding in volume in recent decades (Blindheim, 1990; Blindheim, *et al*., 2000). The Arctic Intermediate water manifests itself as a salinity minimum in the water column and it blankets the entire Norwegian Sea and thus precludes direct contact between the warm surface waters and the dense deep waters ($T<-0.5°C$) whose properties are defined by inflows from the Greenland Sea. The circulation in the deep waters is topographically influenced and clockwise in the two basins. Cold deep water flows out of the Norwegian Sea through the Faroe Bank channel, the deepest connection to the North Atlantic.

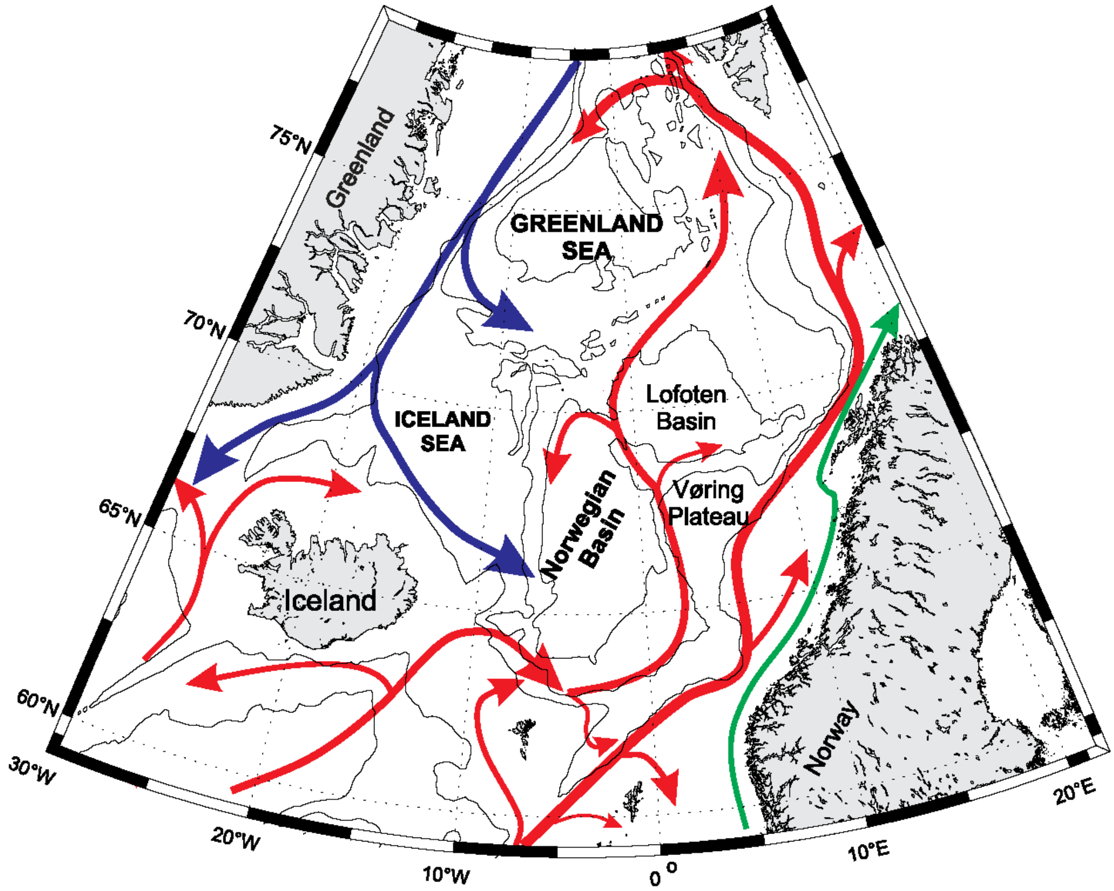

Figure 3.2.3.1 Norwegian Sea main circulation pattern. Red lines indicate warm currents, blue lines indicate cold currents and green lines show low salinity coastal water.

Between Iceland and Jan Mayen variations in the volume of Arctic waters carried by the East Icelandic Current (EIC) may result in relatively large shifts of the front between the cold Arctic waters and the warm Atlantic water. Fluctuations in fluxes and water-mass properties in the two major current systems are therefore of decisive importance for the structure and distribution of the water masses in the Nordic Seas. Generally, a high NAO index with strong westerly winds will result in an increased influence of Arctic waters in the western Norwegian Sea arriving from the EIC. E.g. in the early 1990s the NAO index was high and the Arctic water occupied a larger portion of the Norwegian Sea. The volume of and properties of the Arctic water carried directly into the Norwegian Sea by the EIC play a larger role than previously believed in the creation of variability in the distribution of water masses and their properties in the Nordic Seas (Blindheim *et al*., 2000).

Phytoplankton

The annual rate of primary production in the Atlantic Water has been estimated to be about 80 g C m^{-2} $year^{-1}$ (Rey, 2004). Of this production about 60% is new production, i.e. the remainder 40% of the production is assumed to be based on regenerated nutrients. The new production represents the potential for harvest in the ocean. The spring bloom, defined as the time of the maximum chlorophyll concentration, occurs in the mean around 20th of May, but may occur a month earlier or later. The most important group of phytoplankton is the diatoms, with most of the species belonging to the Order Centralis, and the most important representatives are species of the genus *Thalassiosira* and *Chaetoceros*. After the diatom spring bloom the phytoplankton community is often dominated by the flagellate *Phaeocystis pouchetii*. In the Norwegian Coastal Current the primary production varies from 90-120 g C m^{-2} $year^{-1}$.

Zooplankton

The zooplankton community of the Norwegian Sea is dominated by copepods and euphausids. The main copepod is *Calanus finmarchicus* in the Atlantic water while *Calanus hyperboreus* is the dominant species in the arctic watermasses. The main euphausids are *Meganychthiphanes norvegica*, *Thysanoessa inermis* and *Thysanoessa longicaudata*. Other important zooplankton are the hyperids *Themisto libellula* and *Themisto abyssorum*. The plankton community show varying productivity with concentrations of the most important species *Calanus finmarchicus* varying for instance between about 8 g/m^2 dryweight in 1997 to 28 g/m^2 dryweight in 1995. The highly variable availability of zooplankton is an important factor for fish stocks productivity.

Benthic habitats

Coral reefs formed by the cold-water coral Lophelia pertusa are quite common in the eastern shelf area of the Norwegian Sea. Nowhere else in the world similar densities and sizes of such reefs have been found. The largest reef, or reef complex (comprising several closely situated individual reefs) known as the Røst Reef, is situated south west of Lofoten. Lophelia reefs offers habitats (microhabitats) for a great diversity of other species. Redfish (Sebastes spp.) are common on the reefs. The great abundances of this fish have been known by local fishers for a long time. More recent fishery practice employing rock hopper trawl gear close to or directly on these reefs has led to severe damages. Other corals such as gorgonians also form habitats utilised by fish and other organisms. These habitats are often called “gorgonian forests”, and are common in some fjords and along the shelf break.

Fish communities

The Norwegian Sea fish community is characterised by a number of large stocks of medium sized highly migratory pelagic species exploiting the pelagic zone of the vast areas with large bottom depths, smaller mesopelagic species exploiting the same areas and several demersal and pelagic stocks exploiting and/or spawning in the marginal eastern continental shelf areas. The large stocks exploiting the area for feeding must be regarded key species in the ecosystem. The main pelagic stocks feeding in the area are the blue whiting Micromesistius poutassou, NE Atlantic mackerel Scomber scombrus and Norwegian spring spawning herring Clupea harengus. The herring also spawns in the eastern shelf areas. With regard to horizontal distribution in the feeding areas the herring is the most northern one, mackerel more southern while the blue whiting seems distributed over most of the area. With regard to vertical distribution during the feeding season the mackerel is closest to the surface, the herring somewhat deeper, while the blue whiting as a mesopelagic species with the deepest mean depth distribution. Other important mesopelagic species in the area are redfish Sebastes sp., pearlsides Maurolicus muelleri and lanternfishes Benthosema glaciale. The open Norwegian Sea all way into the polar front is an important nursery areas for the lumpsucker Cyclopterus lumpus and the northeastern shelf areas are important spawning grounds. Local stocks of herring exist in many fjords along the Norwegian coastline. The stocks make limited migration out in to the open waters for feeding.

None of the main pelagic species has its entire life cycle within the Norwegian Sea ecosystem. The blue whiting spawns west of the British Isles and perform a northerly and westerly feeding migration into the Faroes ecosystem and the Norwegian Sea ecosystem. The mackerel spawns west of the British Isles and in the North Sea and performs northerly feeding migrations into the Norwegian Sea. The Norwegian spring spawning herring has its main spawning and feeding areas in the Norwegian Sea while the main nursery and young fish area is in the neighbouring Barents Sea ecosystem.

As pelagic feeders all the three stocks must be expected to have major influences on the ecosystem. Studies on this subject have only been carried out to a limited degree and are mainly of descriptive character. For instance was the highest catches of salmon ever (1970s) taken during a period when the herring stock was at a record low level. This has been suggested to be a potential effect of reduced competition beneficial for salmon stock productivity (Hansen *et al.*, 2000).

The NE Arctic cod Gadus morhua and haddock Melanogrammus aeglefinnus have their main adult feeding and nursery areas in the Barents Sea while the main spawning areas are along the eastern shelf areas of the Norwegian Sea and into the SE parts of the Barents Sea ecosystem. There are local cod stocks connected to the coast and only doing limited migrations from the coast for feeding. The NE Arctic saithe also spawns along the eastern shelf areas of the Norwegian Sea and has important nursery areas on this coastline and into the Barents Sea on the Finmark coast. The migration of older and mature saithe are to a large degree linked with those of the Norwegian spring spawning herring out into the high seas areas of the Norwegian Sea. There are also stocks of ling Molva molva and tusk Bromse brosme along the eastern shelf region. Greenland halibut Reinhardtius hippoglossoides is found along the eastern shelf and also in the shelf areas of Jan Mayen Island. Other important species inhabiting the hydrographic transition zone include roughead grenadier Macrourus berglax, several species of eelpouts zoarcids and the rajiids Raja hyperborean, R. radiata and Bathyraja spinicauda (Bergstad *et al.*, 1999).

The demersal species are in general connected to the eastern shelf area and the presence of the largest stocks is connected to spawning. The fishes then migrate back to the Barents Sea for feeding. The fry also in general drift out of the Norwegian Sea and into the Barents Sea. As compared to the pelagic species the demersal stocks must accordingly be regarded as less significant for the Norwegian Sea ecosystem as a whole.

Seabirds

It is estimated that about 6.1 million seabirds (1.8 million pairs) breed along the Norwegian coast of the Norwegian Sea. In addition about 270 000 pairs breed on Jan Mayen (Barrett *et al.*, 2001). In addition a large number of northern fulmars are spread over most of the Norwegian Sea throughout the year, and a similarly large number of little auks breeding i the Barents Sea winter along the Norwegian coast. Altogether, it is estimated that the total consumption by all marine birds in the Norwegian Sea is nearly 680 000 tonnes. The most typical species are listed below, based on Barrett *et al.*, 2001.

Among the species breeding along the Norwegian coast, the most common is the Atlantic puffin (Fratercula arctica) with about 1 225 000 breeding pairs. Blacklegged kittiwake (Rissa tridactyla) and common eider (Somateria mollissima) are the next most common species with 170 000 and 130 000 breeding pairs, respectively (Barrett *et al.*, 2001).

The most common birds breeding on Jan Mayen are northern fulmars (Fulmarus glacialis), little auks (Alle alle), and Brünnich's guillemots (Uria lomvia).

Marine mammals

There are two seal stocks of particular importance in the Norwegian Sea: Harp and hooded seals. Both species are whelping on the pack ice off the east coast of Greenland (the Greenland Sea or West Ice stocks) in mid to late March (Haug *et al*., 2006; Salberg *et al.*, 2007). During spring, harp seals exhibit a set sequence of activities – birthing (whelping) (in March-April), followed by 12 days of intensive lactation, then mating, after which the females wean their pups. Moulting of adults and immature animals takes place north of each whelping location after a further lapse of approximately 4 weeks. When the moult is over, the seals disperse in small herds to feed along the east coast of Greenland, from the Denmark Strait or farther south, northwards towards Spitsbergen and they also move far into the Barents Sea (Haug *et al*., 2004; Folkow *et al*., 2004). The movements of harp seals towards the breeding areas begins in November-December. Between breeding and moult, hooded seals perform feeding excursions to the continental shelf edges off the Faroe Islands and Northern Ireland, and to areas in the Norwegian Sea. During moult (June/July) the West Ice hooded seals haul out on pack ice north of the breeding area, i.e., northwest of the island of Jan Mayen (Folkow *et al*., 1996). Satellite tracking data have revealed that hooded seals from the West Ice stock appear to occupy ice-covered waters off the east coast of Greenland much of the summer. But, they make long excursions to distant waters (temperate as well as Arctic) such as the waters off the Faroe Islands, the Irminger Sea, north/northeast of Iceland, areas in the Norwegian Sea, and along the continental shelf edge from Norway to Svalbard, presumably to feed, before returning to the ice edge again (Folkow *et al*., 1996). Both species show opportunistic feeding patterns in that different prey are consumed in different areas and at different times of the year. Harp seals feeds primarily on zooplankton (krill and amphipods) and pelagic fish sopecies such as polar cod and capelin, whereas hooded seals feed on squid, polar cod and benthic fish species such as redfish and Greenland halibut (Haug *et al*., 2004, 2007). The Greenland Sea stocks of harp and hooded seals have been commercially exploited and managed jointly by Norway and Russia during the past two centuries. The most recent estimates of abundance suggest that there are approximately 600 000 harp seals and 70 000 hooded seals in the Greenland Sea (ICES 2006, 2007).

Due to topographical and hydrographic characteristics beneficial for production the Norwegian Sea has abundant stocks of whales feeding on plankton, pelagic fishes and Cephalopods. Large whales are visiting the area in summer while representatives of the smaller toothed whales are supposed to stay there all year around.

The minke whale Balaenoptera acutorostrata is the smallest in size and most numerous in stock size of the baleen whales in the Norwegian Sea. It is found throughout the area, in particular along the eastern shelf area and in the Jan Mayen area. The species is an opportunistic feeder with special preference for herring in the Norwegian Sea ecosystem.

Fin whale, Balaenoptera physalus, represents together with the sperm whale, Physeter macrocephalus, the largest cetacean biomass in the Norwegian Sea. In the summer months fin whales are especially abundant along the continental slope from Bear Island northwards to Spitsbergen, supposedly feeding on euphausiids. They are also known to feed on herring and capelin which become more important in spring and fall. There are around 5000 fin whales in the Norwegian Sea. Of the other baleen whales, humpback whale, Megaptera novaeangliae, is quite common with its 1000 individuals. They are also supposed to feed primarily on euphausiids in summer and switching to capelin during fall. Sei whales, Balaenoptera borealis, are usually associated with warmer water masses and are normally found in small numbers only within the Norwegian Sea. Blue whales, Balaenoptera musculus, are regular visitors in low numbers and seem to feed exclusively on euphausiids.

Sperm whales are abundant over the deep waters off the continental slopes south of Bear Island, where they feed on squids and mesopelagic fish. A high density area is found west of Andøya, associated with the bleik canyon. The sperm whales in the Norwegian Sea, numbering about 6000 individuals, are solitary males.

The killer whale Orcinus orca in the area is closely linked to the yearly migrations of the Norwegian spring spawning herring. In the present wintering area of the herring, the Vestfjord, Tysford and Ofotfjord an estimated 500 killer whales have been feeding on herring during the winter months. A total estimate of killer whales for the Norwegian Sea and the Barents Sea it is at some few thousands individuals. Whitebeaked (Lagenorhynchus albirostris) and whitesided (L. acutus) dolphins are common especially in association with the continental slopes. Longfinned pilot whales, Globicephala melas, occur in large groups and are regular visitors to the Norwegian Sea. The northern bottlenose whale, Hyperoodon ampullatus, is an odontocid approximately the size of a minke whale, and occurring over the deep waters in modest numbers. This species is thought to have feeding preferences similar to the sperm whale.

Knowledge gaps

3.2.4 Major significant ecological events and trends

Generally warming climate during the last 28 years with about 0.8ºC increase since 1978 in the Atlantic Water on the Svinøy section. The years 2002–2006 are all warm years and 2006 was the warmest ever in the time series. The salinity has also increased during the last years, and since 2002–2003 it has been record high in both the the Svinøy and Gimsøy sections.

In May 2006 there was an increased influence of Arctic water from the East Icelandic Current, and the upper layer of the western Norwegian Sea was was then about 0.25–0.75°C colder in May 2006 compared to May 2005.

Generally low zooplankton in the central Norwegian Sea for several years.

Large stocks of all major pelagic stocks. The total stock of highly migratory plankton feeders is high.

Changes in herring feeding migration occurred during the summers 2004–2006 when increasing amounts of herring started to feed in the southwestern Norwegian Sea. At the same time only small numbers of herring were wintering in the fjords of northern Norway, and the winters 2005/2006 and 2006/2007 the main wintering area has been off the shelf north of Vesterålen to 72ºN.

3.2.4.1 Fisheries effects on benthos and fish communities

Destruction of deepwater coral reefs has been documented in the eastern shelf areas and has resulted in area closures for bottom trawling. Effects on other bottom fauna could be expected from bottom trawling activities in the eastern shelf areas.

Work is carried out within the framework of ICES in order to sort out the scale of unintentional bycatch of salmon in the pelagic fisheries in the Norwegian Sea (SGBYSAL) but no such major effects have been documented so far.

Mortality of seabirds occurs in longline fisheries. Magnitude and species composition is unknown.

Bycatch of harbour porpoise is routinely observed in net fisheries. In episodes of coastal invasion of arctic seals large mortality of seals has been observed in net fisheries. This mortality has not been regarded as problematic for the state of the seal stocks due to the general good condition and low harvesting level of the stocks.

Mortality of large marine mammals due to bycatch has not been described and is probably low.

Ghost fishing has been documented through dredging of lost gear along the eastern shelf area. A programme for retrieval of such gears is in effect along the Norwegian coast towards the Norwegian Sea, and a high number of ghost fishing nets are retrieved yearly. The need for such activity is probably larger than what is currently carried out, given the fish mortality observed in retrieved nets.

A major collapse in the herring stock was observed during the late 1960s. Various analyses have shown that the fisheries were a major factor driving the collapse.

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