European Environment Agency

Europe's biodiversity
- biogeographical regions and seas

Seas around Europe

The North Sea
- bottom trawling and oil / gas exploitation

Authors:
Mats Walday and Tone Kroglund,
Norwegian Institute for Water Research (NIVA)

Map production:
UNEP/GRID Warsaw (final production)

EEA Project Manager: Anita Künitzer (final edition)

CONTENTS

Summary

- The North Sea is a shallow and rather young ecosystem formed by the flooding of a landmass some 20 000 years ago. Its coasts and waters are still being colonised by new species from the Atlantic.
- The strong coupling between benthic and pelagic communities in the shallow parts of the sea makes it extremely productive and one of the most productive areas in the world, with a wide range of plankton, fish, seabirds and benthic communities.
- The North Sea is one of the world's most important fishing grounds. The sea is also rich in oil and gas.
- Anthropogenic impacts have been significant for many years. The marine ecosystems are under intense pressure from fishing, nutrient input, recreational use and habitat loss; most notable are the effects of fisheries and eutrophication. Until 1995, pollution was the main issue at the North Sea conferences. Over the last decade, there has been an increasing awareness and concern for the impaired status of several of the North Sea fish stocks, as well as the impact of fisheries on other parts of the ecosystem.
- The European Commission has recently developed biodiversity action plans, aiming to integrate biodiversity thinking into the areas of e.g. conservation of natural resources, fisheries and aquaculture.

1 What are the characteristics of the North Sea?

1.1 General characteristics

Table 1: Statistics for the North Sea (including Skagerrak)

Surface area km^2	Water volume km^3	Average Depth m	Surface Temperature°C	Salinity ‰
750 000	94 000	90 max 725	August 12-20 February 0-8	25-35

The North Sea is a large semi-enclosed sea on the continental shelf of north-west Europe, formed by flooding in the Holocene period. The North Sea is bounded by the coastlines of England, Scotland, Norway, Sweden, Denmark, Germany, the Netherlands, Belgium and France, and by imaginary lines delimiting the western approaches to the Channel (5°W), the northern Atlantic between Scotland and Norway (62°N, 5°W), and the Baltic in the Danish Straits (Map 1). The total catchment area is 850 000 square kilometres (km^2). The sea is shallow, getting deeper towards the north. It includes the Skagerrak with depths up to 725 metres (m).

1.1.1 Hydrography

Atlantic water enters the North Sea mainly from the north. The topography produces an anticlockwise circulation. Water entering from the Channel moves eastward along the

Belgian/Dutch coast. In the Skagerrak, the North Sea water mixes with less saline water from the Baltic, and is transported north along the Norwegian west coast. Surface water temperature varies between 0 and 20^{o} C, depending on the season and the part of the sea, with less variation in the north. Salinity displays few variations in the open North Sea (32-34.5 ‰). In the coastal areas of Skagerrak salinity ranges between 25 and 34 and in the Wadden Sea it is usually less than 30. Temperature and salinity show variability at annual, seasonal and decadal scales. Tidal currents vary from some of the strongest in the world to zero. Depressed oxygen levels are found below 70 m.

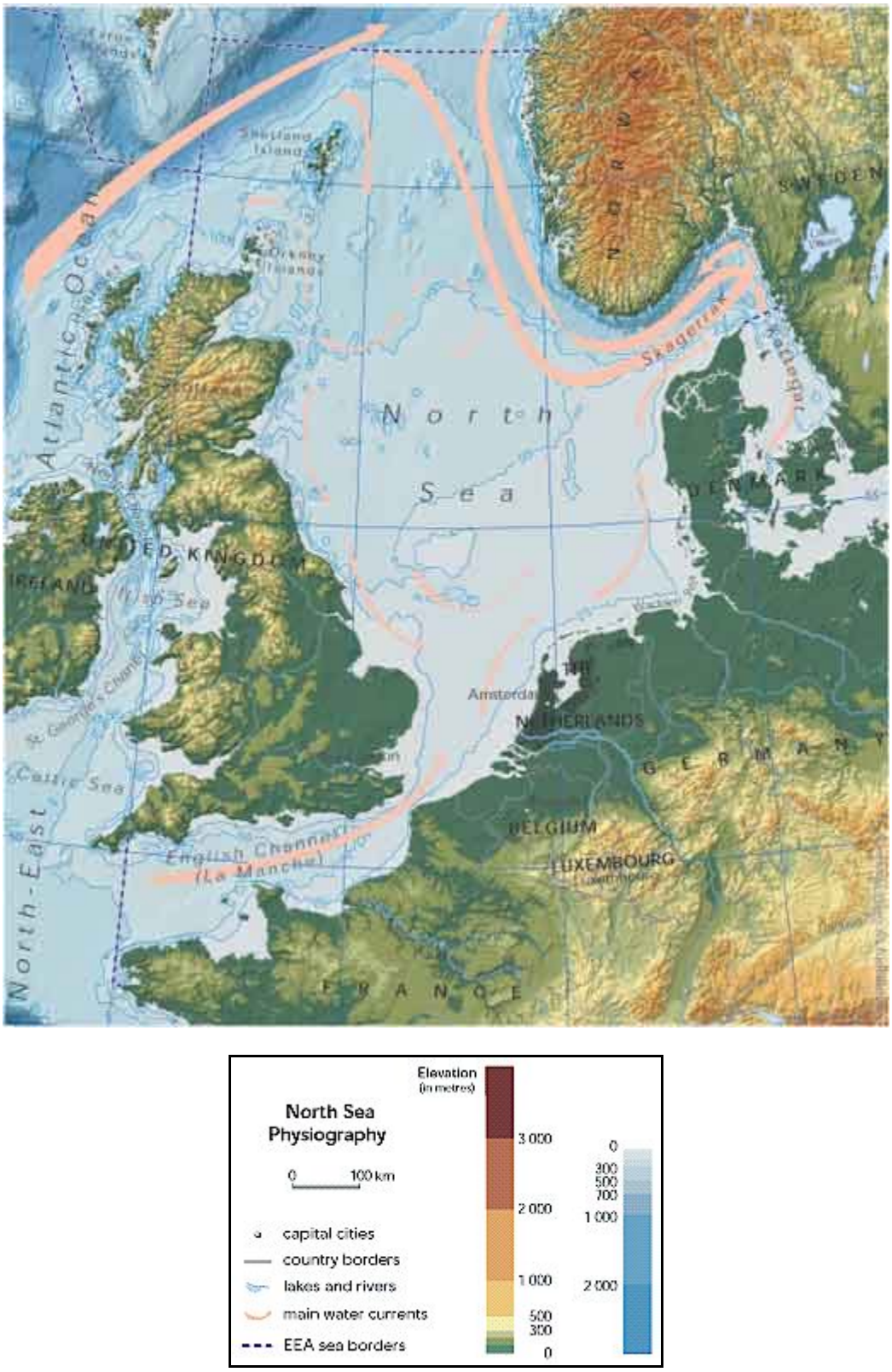
1.1.2 Sea bottom and coastline

The seabeds are predominantly sandy, but muddy in deeper parts and in southern coastal areas with extensive river influence.

The coastlines display a large variety of habitats. In Scotland and Norway the coastlines are mountainous and rocky, often dissected by deep fjords. The Norwegian and Swedish mainland is sheltered from the open ocean by a more or less continuous archipelago. The coasts of northern England and Scotland have a variety of cliffs, pebble beaches, estuaries, sand and mud flats. From the Channel to the Danish west coast sandy beaches and dunes prevail, with numerous estuaries and the tidal inlets and islands of the Wadden Sea. The Wadden Sea extends from the Netherlands to Denmark and is an ecologically important area with extensive mud flats, sheltered by barrier islands. The natural coastline of the Southern Bight has been changed considerably with the development of towns and harbours, land reclamation projects and coastal protection structures.

Erosion and sedimentation along the shoreline are widespread in the central and southern parts of the sea, with more than half of the coastline affected (European Commission, 1998). The low-lying north-western coast of Denmark has some of the most active dune landscapes in Europe. Countries around the North Sea are working to prevent coastal erosion.

Map 1: North Sea physiography (depth distribution and main currents)



Source: EEA. UNEP/GRID Warsaw final map production.

1.2 Main influences

Inputs from industry, agriculture and 184 million people (OSPAR, 2000) in the catchment area, together with impact from extensive fisheries, offshore industry, intense shipping and a growing mariculture activity, put considerable pressure on the ecological systems in the North Sea.

• Fisheries

The North Sea is one of the world's most important fishing grounds. Total landings of fish amounted to roughly 2.3 million tonnes in 1999 (Iversen, 2001).

• Eutrophication

Most sources of nutrients are linked to anthropogenic activities. Major rivers, such as the Rhine, Elbe, Weser, Ems and Thames, discharge into the southern part of the sea. Nitrogen in rivers originates mainly from agricultural soil fertilisation. Phosphorus is mainly linked to urban wastewater and soil erosion.

• Offshore industry

Hydrocarbon resources are rich, and the total production of oil in 1996–98 by Denmark, Germany, the Netherlands, Norway and the United Kingdom was 285.3 million tonnes per year and the total production of gas was 167.7 billion tonnes per year (OSPAR, 2000). Discharges from offshore installations amount to 16–17 000 tonnes of oil per year.

• Maritime traffic

The North Sea contains some of the busiest shipping routes in the world: 270 000 ships entered the main 50 ports in 1996. Shipping increases the risk of oil spills from accidents and illegal discharges of oil.

• Industry

There is a wide variety of industries located along the North Sea coasts (e.g. metal and metal-processing industry, chemicals, shipbuilding and nuclear power plants).

• Tourism

The North Sea also plays an important role as a recreational area for many people. Tourism has increased over the last decade, putting more pressure on the environment.

1.3 Main political instruments

Biodiversity in the North Sea is covered by a number of international agreements at different levels and with different scope:

- Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention);
- Convention for the International Council for the Exploration of the Sea (ICES);
- Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) and the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention);
- Trilateral Wadden Sea Cooperation;

- International Conferences on the Protection of the North Sea (North Sea Conference);
- EU Birds and Habitats Directives;
- Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention);
- Ramsar Convention.

1.4 Biodiversity status

The North Sea belongs mainly to the boreal biogeographical sea region (see introductory chapter).

1.4.1 Plankton and benthos

• Plankton

Phytoplankton (diatoms, dinoflagellates and other flagellates) is the main primary producers at sea. Physical factors, particularly water stratification, play a significant role in structuring the pelagic ecosystems of the North Sea. The phytoplankton of the open sea is mainly light-limited in winter, and nutrient-limited in the water above the thermocline in summer (OSPAR, 2000). Diatom and flagellate populations fluctuate with different annual cycles, with particularly large seasonal fluctuations in summer dinoflagellate stocks.

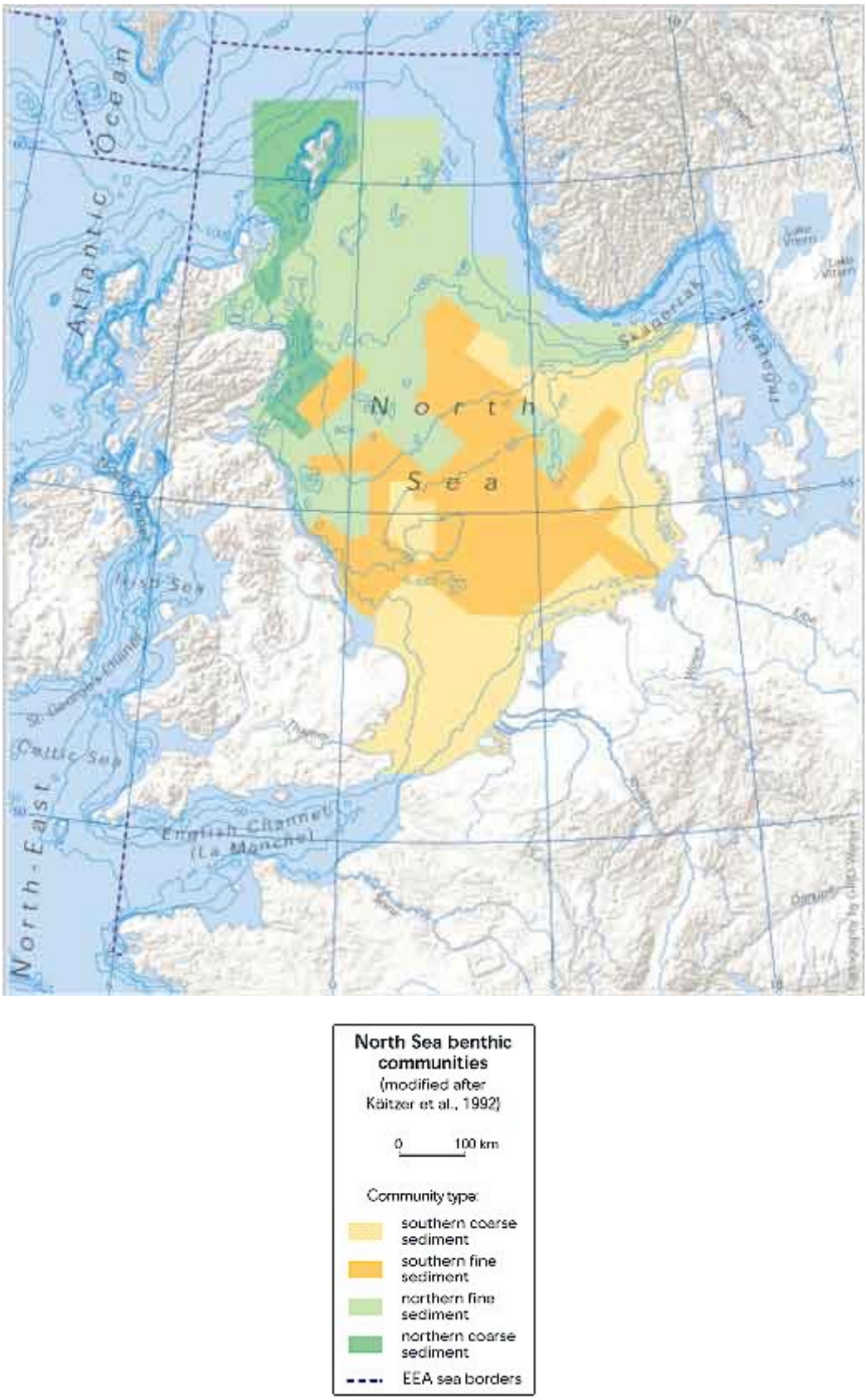
The phytoplankton is grazed by the zooplankton. Small crustaceans make up to 70-80 % of the total zooplankton biomass, *Calanus* being the most abundant genus. It enters the North Sea by drifting with water masses from the north. Generally, zooplankton abundance peaks about two weeks after phytoplankton abundance (Fransz *et al*., 1991).

• Benthos

The benthos consists of the organisms living near, on, or in the seabed. A wide variety of animals belong to the benthic community: crustaceans, molluscs, annelids, echinoderms and others. As the North Sea is shallow, there is a strong coupling between benthic and pelagic processes, making the region extremely productive. The diversity of the offshore benthic communities is high, except in areas of direct industrial impact, such as offshore oil fields.

Benthic communities have been investigated since the early 1900s, including major studies around Denmark and the United Kingdom. The diversity of benthic communities is described by Künitzer *et al*. (1992) (Map 2), by the Joint Nature Conservation Committee, United Kingdom (e.g. Picton and Costello, 1998; Hiscock, 1998), and by ICES in the *Atlas of North Sea benthic fauna* (Craeymeersch *et al*., 1997).

Map 2: North Sea benthic communities



Source: Modified from Künitzer et al., 1992

Case study: 1986 North Sea benthos survey

A 1986 survey, covering the whole of the main North Sea basin (Heip *et al.*, 1992), showed clear north-south differences in diversity, abundance, biomass and average individual weight of the soft-bottom fauna. The deeper northern regions had higher diversity, lower biomass, and lower individual weights than the shallow southern regions. The main causes are thought to be differences in the size distribution of the sedimentary grains, and the supply to the bottom of organic matter from the pelagic primary production. In particular it appears that the benthic-pelagic coupling is stronger in the more shallow southern areas. There can be considerable short-term temporal changes in the diversity and structure of the benthic community in the central part of the North Sea (Pearson and Mannvik, 1998). This variability may be driven by climate-induced fluctuations in the overlying pelagic communities.

Most of the seabed in the North Sea hosts soft-bottom communities (Map 2) apart from the land margins of Norway and the United Kingdom where rocky shores dominate. Rocky shores have the most developed macroalgal communities in the region, with vegetation down to approximately 15 m in the southern part and 30 m in the northern part of the sea (OSPAR, 2000). Kelp forests are widespread on rocky sublittoral areas in the northern part of the region and many species of flora and fauna find shelter, food and surfaces for attachment on the kelp and the surrounding rocky substrate. Different communities develop, depending on factors such as exposure, turbidity, grazing pressure and substrate type. Different species directories list about 820 macroalgal species for the British Isles and the surrounding seas, 370 for the Norwegian coastline, 325 for the northern part of Kattegat, 274 for Helgoland and 230 for the Netherlands (Bartsch, 2000).

Benthic microalgae are a primary source of nutrition in shallow waters for larger grazers and fish like the mullet (OSPAR, 2000). These algae, suspended by wave action, constitute up to 90 % of the primary production in these waters.

Photo: Kelp forests are in many ways similar to tropical rainforests

Source: Are Pedersen, NIVA

1.4.2 Large fauna

• Fish

Approximately 230 species of fish inhabit the North Sea. The distribution and abundance of many of these is described by Knijn *et al*. (1993). Diversity is low in the shallow southern North Sea and eastern Channel, and increases westwards (Rogers *et al*., 1998). Species diversity is also generally higher inshore (Greenstreet and Hall, 1996) as there are more varied sediment types and spatial niches. Most of the variability of the fish stocks is due to variation in egg and larval survival. Stocks are also influenced by intense fishing. Most species show annual or seasonal migrations related to feeding and spawning.

• Seabirds

The bird populations of the North Sea area are of global importance. There are 31 species of seabirds breeding along the coasts and major seabird colonies living along the rocky coasts in the northern part of the North Sea. Some 10 million seabirds are present at most times of the year, but migrations and seasonal shifts are pronounced, and none of the species is endemic. Many shorebirds, such as waders and ducks, feed in inter-tidal areas along the coast. The Wadden Sea is of particular importance for both breeding and migratory populations, with 6 to 12 million birds of more than 50 different species present every year (OSPAR, 2000).

Case study: Great skua

The North Sea coasts support more than 50 % of the world's common terns and great skuas (*Catharacta skua*). A further twelve species, such as the common scooter around the Flemish Banks, are present in numbers exceeding 10 % of their total estimated populations (OSPAR, 2000).

Photo: Great skua (*Stercorarius skua*)

Source: Benny Gensbøl/ Biofoto. Danmark (BG 827)

• Marine mammals

Three species of seal and 16 of whale are more or less regularly observed in the North Sea (OSPAR, 2000). The grey seal (*Halichoerus grypus*) and the harbour seal (*Phoca vitulina*) both breed in the area. The grey seal is most abundant in exposed locations in the north-west, while the harbour seal is more widespread, often found on mud and sand flats. The harbour seal population in the North Sea has recovered from a severe epidemic of viruses

in 1988. The most frequently observed cetacean is the harbour porpoise (*Phocoena phocoena*). Other species of toothed cetacean that are sighted regularly include long-finned pilot whales (*Globicephala melas*), the common dolphin (*Delphinus delphis*), the white-sided dolphin (*Lagenorhynchus acutus*), Risso's dolphin (*Grampus griseus*) and the killer whale (*Orcinus orca*). Sightings of other species are relatively rare (OSPAR, 2000).

1.4.3 Special habitat types

Most of the Wadden Sea, particularly in the Netherlands and Lower Saxony, is sheltered by barrier islands and contains inter-tidal flats of great importance to wildlife. The flats contain few species but are extremely productive, supporting vast numbers of waders and wildfowl; around 10 million birds pass through the region each year. These areas are also an important nursery ground for North Sea fish stocks. Inter-tidal flats around the British Isles are less extensive but critically important for many species. This is because the mild winter conditions and large tidal range expose large areas, which allows winter access to food for waders and wildfowl (Gubbay, 1995).

Estuaries are normally defined as the downstream parts of rivers where freshwater meets seawater and salinity increases towards the open sea. They often have extensive mud and sand flats and are found mostly in the southern regions of the North Sea. Nine different types of estuaries are classified in the United Kingdom. Thirty-seven different major marine communities have been identified within these estuaries (Davidson et al., 1991). In general, estuarine habitats contain fewer species than marine habitats, because of their reduced salinity.

1.5 Fisheries and other marine living resources

The North Sea is one of the world's most productive areas for fish and a large number of commercially important species are caught in this area. The total biomass of all fish in the North Sea is estimated at approximately 10 million tonnes. The total landings of different fish species in 1999 amounted to roughly 2.3 million tonnes (Iversen, 2001). Herring and mackerel are currently the most important species (OSPAR, 2000).

Table 2: The most important commercial species in North Sea fisheries, their habitat, and their use as human food or for fish meal and fish oil

Species		Status of stock	Habitat	Use
Cod	*Gadus morhua*	osbl	demersal	food
Haddock	*Melanogrammus aeglefinus*	csbl	demersal	food
Whiting	*Merlangius merlangus*	osbl	demersal	food
Saithe	*Pollachius virens*	osbl	demersal	food
Plaice	*Pleuronectes platessa*	osbl	demersal	food
Sole	*Solea solea*	osbl	demersal	food
Mackerel	*Scomber scombrus*	osbl	pelagic	food
Horse mackerel	*Trachurus trachurus*	?	pelagic	food
Herring	*Clupea harengus*	osbl	pelagic	food
Norway lobster	*Nephrops norvegicus*	?	demersal	food
Deep-water prawn	*Pandalus borealis*	?	demersal	food
Norway pout	*Trisopterus esmarkii*	?	Demersal[1]	industry
Sprat	*Sprattus sprattus*	?	pelagic	industry
Sand eel	*Ammodytes* spp.	?	Demersal[2]	industry

Note: Status of stock: osbl - outside safe biological limit; csbl - close to safe biological limit.
[1] Sometimes pelagic
[2] Pelagic feeding

Source: ICES, 1999

The major commercial crustacean in the North Sea is the Norway lobster (*Nephrops norvegicus*) with landings between 12 000 and 20 000 tonnes per year. The total landings of prawns *Pandalus borealis* and *Crangon crangon*) amount to 45 000 tonnes per year (OSPAR, 2000).

Fishing activities for molluscs such as scallop, cockle, blue mussel, common whelk, winkle and clam species are concentrated to the east coast of England, the French Channel coast and the Wadden Sea. In the Thames estuary cockle fishing amounts to between 10 000 and 25 000 tonnes per year.

Seaweed and kelp (*Ascophyllum nodosum, Laminaria hyperborea and L. digitata*) are harvested for industrial purposes (alginate production) along the west coast of Norway, the French Channel coast and along some parts of the UK coast. The total amount of *L. hyperborea* harvested in the Norwegian part of the North Sea was on average 70 000 tonnes per year from 1995 to 2000. In France, 57 000 tonnes of kelp and 15 000 tonnes of wrack (*Fucus* sp.) were harvested in 1996 (OSPAR, 2000).

Several species of calcified red seaweed occur in the region and a number of these form maerl beds. Maerl has been commercially exploited in the North Sea since at least the 18th century, mainly because of its value as a soil conditioner. This supports an important industry in Brittany (Gubbay, 1995).

2 What is happening to biodiversity in the North Sea?

Many human activities have an impact on the biodiversity of the North Sea, but most notable are the effects of fisheries and eutrophication.

2.1 Fisheries

The relatively shallow waters of the North Sea have supported fisheries for many centuries and although they continue to do so, the species that are the focus of the fisheries have changed as landings and stocks have declined. The most important effects of fishing on North Sea ecosystems are:

- mortality of target- and non-target species;
- organic input from discarded catch and fish offal;
- physical damage of habitats.

• Overfishing

At various times during the past 10 years the North Sea stocks of cod, haddock, whiting, saithe, plaice and herring have dropped to, or below, any previously recorded level (Svelle *et al*., 1997). All the major stocks are considered by ICES to be close to or below safe biological limits (Table 2). Herring stocks are now increasing after the rigorous regulation of fisheries of recent years (Iversen, 2001). The North Sea mackerel stock collapsed in the early 1970s and has still not recovered. However, mackerel from southern European (Portugal and Bay of Biscay) and western European areas (west of Iceland and United Kingdom) migrates after spawning in July to the Norwegian Sea and the North Sea. The mackerel feed in these areas until the next January–March before returning to the southern and western spawning areas. For the stocks of the non-target species, recent investigations indicate few clear trends in the stock sizes of the non-target species (ICES, 1998). Fishing mortality is, however, a selective force that can eventually affect the genetic composition of a target population, as shown for cod by Law and Rowell (1993).

Status of overfishing in the North Sea

Most of the stocks of the commercial fish species in the North Sea are in a seriously endangered condition:

- Between 30 and 40 % of the biomass of these species is caught each year.
- About 70 % of two-year-old cod die before sexual maturity.
- Fisheries cause 80 % of premature mortality.

• By-catch

There is a by-catch problem concerning small cetaceans, particularly the harbour porpoise. Estimates yield an annual by-catch of at least 7 000 animals (OSPAR, 2000). It is likely that the by-catches pose a risk to the population and action is needed to reduce them (ICES, 1999). By-catch might be greatly reduced by the use of acoustic deterrents (‘pingers’). However, there are also problems with by-catch of fish species not targeted by the

respective fisheries, and these catches are usually discarded. It has been estimated that more than 500 000 tonnes of fish per year are discarded in the beam trawl and roundfish fishery in the North Sea (OSPAR, 2000). The by-catch of haddock, whiting and herring is, however, thought to have minor impact on the stocks, responsible for 2 to 4 % of the total mortality (ICES, 1999).

• Discard

The practice of discarding different fish species increases the organic input to the area, and may significantly affect the ecology of scavengers and predators (OSPAR, 2000). In certain fisheries more than half of the weight of the fish caught, as well as considerable amounts of benthos, may be discarded. About 12 % of the weight of landings of fish that are gutted is offal. Discards and offal provide a source of food for seabirds (e.g. gulls and gannets) and are a likely cause of some population increases. Seabirds are estimated to consume about half of all the material discarded (Camphuysen *et al*., 1993).

• Effects on benthos

Fishing gear, specially the beam trawl, may cause damage to substrates and benthic habitats by altering sediment structure and destroying benthic organisms; few areas of the North Sea are unfished and undamaged by demersal trawling (Frid *et al*., 1999). Structural changes may have long-term negative effects on the structure and productivity of the benthic community:

- shifts from larger, longer-lived benthic species to smaller more opportunistic species (Svelle et al., 1997; Lindeboom and de Groot, 1998);
- decrease in the abundance of gadoids and increase in flatfish, resulting in increased predation pressure on the benthos (ICES, 1999);
- attraction of demersal bottom feeders, such as cod and plaice, to the trawling sites. These often feed on benthic invertebrates, which are apparently made more susceptible to predation by damage from trawling.

These indirect effects on fish diets and benthic predation rates result in changes in the nutritional dynamics and community structure, which are important determinants of the functioning of the benthic ecosystem (OSPAR, 2000).

Studies of the effects of fisheries on the benthos are complicated because fishing disturbance has been occurring for more than 100 years and trawling is not distributed homogeneously. Some areas of the bottom are visited more than 400 times a year, and others not at all (Rijnsdorp *et al*., 1996). The ecological impact of towed fishing gear depends on the relative magnitude of fishing and natural disturbance; the effects of fishing are harder to detect on mobile sediments in shallow water than on more stable sediments in deeper water (Kaiser and Spencer, 1996).

Case study: Effects of bottom trawling on benthos

Long-term changes in the composition and abundance of the macrobenthos have been demonstrated on a heavily fished ground off the north-east coast of England (Frid *et al*., 1999). Two benthic stations have been monitored since 1971, and the registered difference in the community dynamics of the two stations, which differ in trawling intensity, provides some evidence of the role of fishing in determining the quantitative and qualitative structure of benthic macrofauna. Seasonal variability in fauna composition was greatest when fishing was at its most intense. Increased variability in composition is thought to be indicative of a stressed community (Warwick and Clarke, 1993).

2.2 Kelp harvesting

Kelp harvesting in Norway is causing concern. The highly diverse kelp forests function as nursery areas for several commercial fish species that feed on the associated fauna of the kelp. Although harvesting is regulated to ensure regrowth of the kelp, its frequency (every fifth year in the same area) is too high to allow the associated flora and fauna community to develop completely (Christie et al., 1998). Another concern, not yet properly substantiated, is the role of the kelp forests as a buffer against wave erosion of the shore. In some shallow areas the kelp may dampen wave action and prevent the loss of sandy shore areas lying behind the forests.

2.3 Fish farming

Fish farming may degrade benthic communities through increased deposition of organic matter and eutrophication by nitrogen and phosphorus emitted from fish cages. Pesticides and antibiotics are used to protect farmed fish along the North Sea coasts. Most of the antibiotics persist in the environment and may accumulate in sediments. Recent data suggest that antibiotic-resistant bacteria are evolving rapidly in the vicinity of fish farms (Kerry *et al*., 1996).

Genetic effects of fish farming on wild stocks is an issue mainly related to Atlantic salmon; escaped salmon have been found to make up more than half of the individuals in several rivers in Norway where the natural stocks are low.

Increases in the amounts of farmed Atlantic salmon have resulted in a clear increase of fish lice. These parasites may cause problems for wild fish stocks. Sea trout seem to be particularly heavily infected and this may be one reason for the observed decrease in populations of sea trout and salmon in Norwegian waters (OSPAR, 2000).

Photo: Salmon fish farm, Norway

Source: Steen Lund/Biofoto. Danmark (SL 3525)

Case study: Landings from fisheries and production from fish farms in the North Sea

Combined landings of different fish species in 1995 amounted to 3.47 million tonnes, an increase of 1.1 million tonnes compared to 1990. In 1999 landings fell again to the 1990 level.

- In 2001 the herring spawning stock is expected to be 5 million tonnes. In 1977 the herring fishery was closed after a drastic decrease in stock from 14 million tonnes in 1950 to 50 000 tonnes in 1972. The fishery was reopened in 1981.
- Total landings of Norway lobster in the North Sea increased gradually from 8 000 tonnes in 1985 to 14 000 tonnes in 1994. Today the total is between 12 000 and 20 000 tonnes per year.
- The total production of salmon in fish farms (mainly Norway and Scotland) increased from 70 000 tonnes in 1990 to 148 000 tonnes in 1996.

Sources: OSPAR 2000; www.imr.no; www.oceanlaw.net/texts/herring1.htm

2.4 Contaminants

The ecological effects of contaminants are often very difficult to assess, with the exception of organotin compounds. Low concentrations of the anti-fouling component tributyltin (TBT), widely used on larger ships, are seriously affecting a wide range of molluscs on coasts all over the North Sea. The effects include shell thickening in Pacific oysters and imposex in gastropods (OSPAR, 2000). Studies of marine snail stocks in German North Sea coastal waters show decreases in the abundance of most species, which may be partly attributed to TBT (Nehring, 1999). There is also increasing evidence of links between contaminants and health effects, e.g. concentrations of polycyclic aromatic hydrocarbons (PAHs) and liver tumour in flatfish, and polychlorinated biphenyls (PCBs) and impaired reproduction in harbour seals in the Wadden Sea. Copper is another contaminant known to induce biological effects. Rygg (1985) found reduced diversity in soft-bottom fauna in Norwegian fjords contaminated by copper. The number of species was roughly halved for each 10-fold increase in the copper concentration in the sediments. Studies have shown that effluents of sewage treatment plants induce oestrogenic effects in fish. The number of synthetic compounds is increasing, and the ecological effects are largely unknown.

2.5 Offshore activities and shipping

The main uncertainty in evaluating the environmental impact of offshore petroleum fields is in assessing the potential effects of the large volumes of produced water that are discharged to the sea. The seawater is separated from the oil but is contaminated by heavy metals, PAHs and production chemicals. The produced volume of seawater is expected to increase considerably as the fields get older, and is already the largest source of hydrocarbon input to the sea from offshore activities. In 1996 oil in produced water represented 80 % of the total oil discharge to the sea on the Norwegian shelf (SFT, 1997). A basic problem in assessing the threat of this source of pollution is the lack of satisfactory methods for monitoring biological effects in the pelagic habitat. Major oil-spills from the sinking of tankers and illegal discharges pose threats mainly to seabirds.

Photo: Oil platform: Monitoring of benthic fauna close to an oil rig in the North Sea

Source: Akvaplan-NIVA

2.6 Eutrophication

Eutrophication is resulting from nutrient enrichment; primarily nitrogen and phosphorus. In the greater North Sea it affects mainly the coastal zone, particularly estuaries and fjords. Nutrient-related problems are widespread in the Wadden Sea, the German Bight, the Kattegat and the eastern Skagerrak (Ærtebjerg *et al*., 2001). The occurrence of low oxygen levels in seawater is highly dependent on hydrographical conditions, and is a problem only in some areas of the North Sea.

Changes in benthic populations are correlated with changes in eutrophication level (OSPAR, 2000). Benthic biomass in muddy areas of the German Bight has tripled during the past 10 years, perhaps partly because of eutrophication. In the Wadden Sea, dense macro-algal mats of green algae reduce the oxygenation of sediments, and in the Ythan Estuary in Scotland the adverse impact of algal mats on invertebrate assemblages has been well documented (Raffaelli, 2000).

Nanoplankton populations appear to have increased steeply at the end of the 1970s (Hickel, 1998), and phytoplankton levels off the north-east coast of England have been increasing over the past 27 years (Frid *et al*., 1999).

Case study: Disappearance of seagrass beds

After an epidemic disease caused by the protozoan *Labyrinthula macrocystis* in the early 1930s, vast subtidal seagrass beds almost completely disappeared from the Wadden Sea, and were unable to re-establish themselves. Although there has been some local re-establishment of another eelgrass species, the overall population decline has continued. One possible cause of this further decline is eutrophication (De Jong *et al*., 1999).

Photo: Seagrass bed

Source: Copyright JNCC

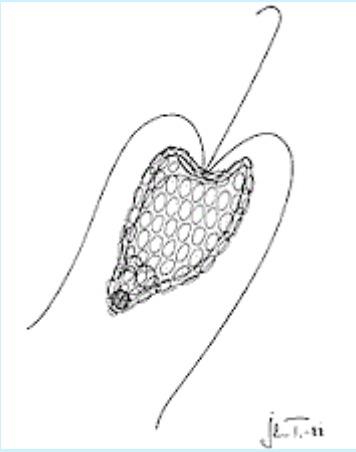
Approximately 20 North Sea phytoplankton species produce toxins. The occurrence of harmful algal blooms is favoured by the ability of several algae to form resting stages.

These reproduce under suitable environmental conditions, and are easily spread in the ballast water of vessels or in aquaculture products such as mussels and oyster larvae. Increased incidence of harmful algal blooms is a possible consequence of eutrophication. There is, however, no evidence of increased incidence in the North Sea over the past 5-10 years (OSPAR, 2000).

Case study: Toxic algal blooms

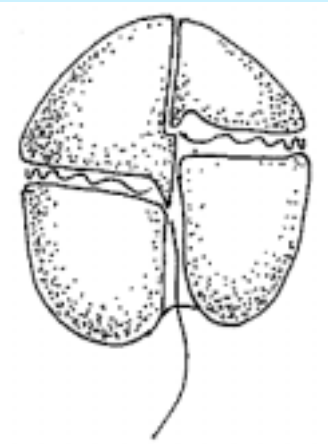
- A strong bloom of *Chrysochromulina polylepis* started in Kattegat and eastern Skagerrak in spring 1988 and spread westwards with the coastal current before it came to rest off south-western Norway. The bloom originated in water with elevated nutrient concentrations and altered nutrient ratios, suggesting a connection between this bloom and eutrophication (Skjoldal and Dundas, 1991). The bloom caused mass mortality in fish cages as well as among natural populations of marine organisms, and generated tremendous public interest.
- The dinoflagellate *Karenia mikimoti* (syn. *Gyrodinium aureolum*) was first observed in northern European waters in 1966 and has since become one of the most common dinoflagellates in the autumn. Since 1981 there have been frequent blooms of this species, often resulting in significant mortalities of farmed fish.
- In the summer of 1997 the alga *Fibrocapsa japonica* was found in almost all samples from the Dutch algal bloom programme. The toxin fibrocapsine produced by this alga has been found in dead seals in Germany, and accumulation of fibrocapsine through the food chain may have contributed to the large numbers of ill and underfed young seals in the Dutch Wadden Sea during the summer of 1998.

Illustration:
Chrysochromulina polylepis



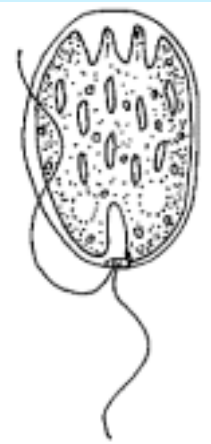
Source: Jan Throndsen

Illustration:
Karenia mikimoti



Source: Petter Wang

Illustration:
Fibrocapsa japonica



Source: Petter Wang

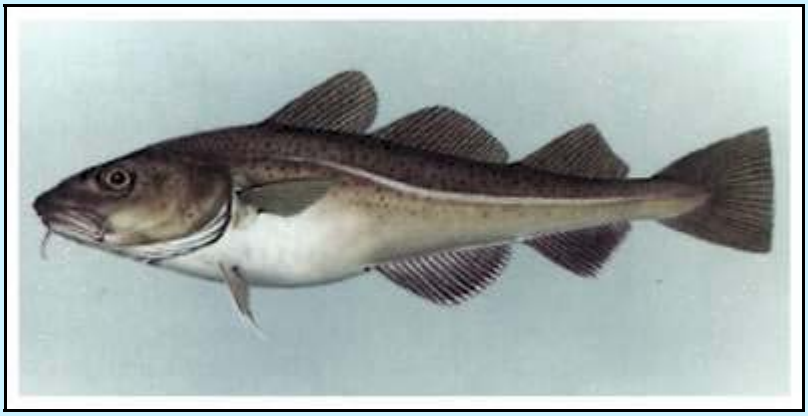
2.7 Climate changes

Time series from the Norderney offshore area and the Kattegat show a correlation between population dynamics and certain climatic factors such as the North Atlantic Oscillation (Tunberg and Nelson, 1998). The increase in macrobenthic abundance in the early 1980s in the Wadden Sea, eastern North Sea, Skagerrak and Kattegat may be linked to climatic changes or eutrophication (Frid *et al*., 1999). Svendsen *et al*. (1995) also demonstrated that climatic factors have a significant impact on recruitment of several commercial fish stocks and on the feeding migration of western mackerel to the North Sea.

Case study: Cod and climate change

There has been a change in the production of young cod that has paralleled warming of the North Sea over the past decade (O'Brien *et al*., 2000). Since 1988, mean sea temperatures during winter and spring have been higher than during the three previous decades. In this period annual recruitment of cod has been low, except in 1996, when cold conditions prevailed. The combination of fishing pressure and warm conditions endangers the sustainability of the cod in the North Sea, and this calls for an immediate reduction in fishing (see Section. 3.2 below).

Illustration: Cod



Source: Norwegian Seafood Export Council

The rise in sea level that is predicted to result from climate change will particularly affect low-lying areas, such as the Dutch, German and Danish coastal zones, south-east England, and the mid-Channel ports in England and France.

2.8 Constructions

Coastal defence work and land reclamation is a common activity in the greater North Sea, particular around its shallow southern and eastern margins. Some coastal defence actions may lead to the destruction of the natural beach through increased deposition at some localities and enhanced erosion at others (OSPAR, 2000). Only five estuaries in the Wadden Sea area have remained. Two have retained their natural character; the remaining three have been considerably modified by diking and deepening. The anthropogenic impact on these estuaries is still increasing. As a consequence, there are hardly any natural transitions of fresh and salt water left in the Wadden Sea area (De Jong *et al*., 1999). Land reclamation has probably been the most serious threat to the inter-tidal flats, but there are also problems associated with dredging, landfill, industrial pollution and other activities.

Land reclamation

More than 32 000 hectares of the German Wadden Sea have been reclaimed since 1963 and in the United Kingdom some areas have lost up to 90 % of their inter-tidal area to land reclamation (Gubbay, 1995).

Seagrass beds are important nursery areas for juvenile fish, but the plants also help to stabilise the sediment and are an important source of organic matter. They are vulnerable to damage from a variety of activities, including dredging, anchor damage and trample.

Decline of mussel beds and seagrass

In the Wadden See, fixed coastal constructions are one of the main causes of the continuing decline in number and size of mature beds of the blue mussel and seagrass meadows during the past decade. The decrease of these structure-building communities is also thought to influence hydrology and sediments in the tidal area (De Jong *et al*., 1999).

Photo: Blue mussel bed

Source: NIVA

2.9 Alien species

Non-indigenous species may arrive in the North Sea as a result of natural and human-mediated processes, e.g. currents, ship ballast water, transport of fish and shellfish, organisms attached to ship hulls and mariculture. More than 80 species have been introduced to the North Sea (Reise *et al*., 1999). Some of these alien species were introduced hundreds of years ago, such as the sand-gaper *Mya arenaria*.

Case study: Examples of recently introduced species

- The brown alga *Sargassum muticum* was probably introduced via shipments of the Japanese oyster (*Crassostrea gigas*) for mariculture in France in the early 1970s (Critchley, 1983). This brown alga has spread widely along the coastline of other North Sea countries. It can grow up to 10 m in length and sometimes clogs bays and harbours. It also competes with other macro-algae for space. There is a continuing expansion of this alga in Scandinavia.
- The Japanese oyster (*Crassostrea gigas*) has spread over the Wadden Sea area. In the late 1990s several local populations thrived in the lower inter-tidal area of the Dutch and German Wadden Sea (OSPAR, 2002)
- The North American razor clam (*Ensis americanus*) and polychaetes of the *Marenzelleria* species group were probably introduced in ship ballast water.

Photo: Japanese oyster (*Crassostrea gigas*)

Source: Knud Garmann/Biofoto. Danmark (KG 9035)

The Joint Nature Conservation Committee (JNCC) in the United Kingdom has prepared an overview of alien marine species in British waters, and their potential impact on the environment (http://www.jncc.gov.uk/marine/default.htm). The list describes more than 50 non-native marine species.

3 Policies at work in the North Sea

3.1 Nature protection

3.1.1 International collaboration

Biodiversity in the North Sea is covered by a number of international agreements at different levels and with different scope. The following conventions/agreements are particularly relevant for biodiversity in the North Sea.

- **OSPAR**

The North Sea is one of five marine regions covered under the 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic. In 1998 a new Annex V to the OSPAR Convention, on the protection and conservation of the ecosystems and the biological diversity of the maritime area, was adopted.

- **ICES**

A major activity of the International Council for the Exploration of the Sea (ICES), as an intergovernmental marine science organisation, is to provide information and advice to member country governments, international regulatory commissions and the Common Fisheries Policy on the protection of the marine environment and the regulation of fisheries.

- **ASCOBANS and the Bonn Convention**

Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBAN) was concluded in 1991, under the auspices of the Bonn Convention on the Conservation of Migratory Species of Wild Animals (UNEP/CMS) to coordinate and implement conservation measures for dolphins, porpoises and other toothed whales in the Baltic and North Seas. Currently eight European countries – Belgium, Denmark, Finland, Germany, the Netherlands, Poland, Sweden and the United Kingdom – are Parties to the Agreement.

- **Trilateral Wadden Sea Cooperation**

Since 1978, the Netherlands, Germany and Denmark have been coordinating their activities and measures for comprehensive protection of the Wadden Sea National Park.

- **North Sea Conference**

The international conferences on the protection of the North Sea are political events for a broad and comprehensive assessment of the measures needed to protect the North Sea environment. The conferences result in ministerial declarations. The 5th North Sea Conference was held in March 2002 in Bergen, Norway.

- **EU Birds and Habitats Directives**

All countries bordering the Celtic Sea, the Bay of Biscay, the Iberian coast and the open ocean areas in the North-East Atlantic are parties to the EU birds and habitats directives in creating the NATURA2000 network of sites of European importance for habitat type and species protection. Many large areas, especially along the coasts, are designated or proposed for designation as NATURA2000 areas.

- **Bern Convention**

The Bern Convention (the Convention on the Conservation of European Wildlife and Natural Habitats) plays a similar role to NATURA2000, particularly for non-EU countries such as Norway. The Bern Convention's main objectives are to protect wild flora and fauna and their natural habitats, and to draw attention to endangered species.

Recent initiatives under the policy instruments listed above, and progress resulting from these initiatives, include:

- revision of the European Union Common Fisheries Policy;
- the 1998 adoption of the new Annex V to the OSPAR Convention on protection and conservation of ecosystems and biological diversity of the marine area;
- the North Sea states agreement on a 50 % reduction of the nutrient inputs to areas affected or likely to be affected by elevated levels of nutrients;
- guidelines from ASCOBANS to minimise acoustic disturbance to marine mammals;
- the increase in the eelgrass stand in the Ems estuary from 13 to more than 100 hectares in the past 10 years, partly due to protection from damage by shell fishery (OSPAR, 2000);
- an overall increase in cetacean strandings in the North Sea, related to an increase in population size due to their protected status;
- an increase in the population size of many seabird species, mainly due to improved protection during the breeding season, a substantial reduction in egg collection and reduced levels of pollutants (De Jong *et al*., 1999). Increased populations of small prey fish and increased supply of discards from fishery may also be contributing factors;
- implementation, albeit slow, of NATURA2000, now nearing completion.

3.1.2 Protected areas

Most of the North Sea marine protected areas (MPAs) are in the southern-eastern parts of the area, along the Wadden Sea coasts of Denmark, Germany and the Netherlands. Most of this area is now under legal protection as the Wadden Sea National Park. This contrasts with the western and northern parts of the North Sea, where there is only one small voluntary MPA. There are no MPAs in the central part of the North Sea. The whole North Sea has however been declared a special area under Annex V of the MARPOL Convention (the International Convention for the Prevention of Pollution from Ships) which prohibits release and disposal of garbage and other domestic wastes from ships.

OSPAR, in collaboration with relevant scientific institutions including ICES and the European Environment Agency (EEA), will assess which habitats in the OSPAR area need to be protected. The OSPAR Working Group on Impacts on the Marine Environment (IMPACT) has recently developed criteria for the selection of marine species and habitats for protection.

Countries are designating main coastal areas and some marine areas, mainly close to the shore, for protection under the global Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat, the European Bern Convention and the EU birds and habitats directives.

Table 3: Number and area of marine and coastal protected areas in the North Sea (EU Birds and Habitat Directives)

	No of areas (SPA+pSCI)	Total area (ha)
Belgium	5	30 700
Denmark	32	342 600
France	58	291 900
Germany	15	103 700
Netherlands	27	773 200
Sweden	30	33 300
UK	129	621 700

SPA= special protected area
pSCI= potential sites for community interest

3.1.3 Red List species

IUCN, the International Union for Nature Conservation, lists globally threatened species of plants and animals. In addition, Fishbase (www.fishbase.org) provides easy accessible lists of threatened marine species. Among listed species, the most relevant for the North Sea are:

- Critically endangered: sturgeon (*Acipenser sturio*).
- Endangered: grey seal (*Halichoerus gryphus*), black right whale (*Eubalaena glacialis*), fin whale (*Balaenoptera physalus*), blue skate (*Dipturus batis*), basking shark (*Cetorhinus maximus*) and Atlantic halibut (*Hippoglossum hippoglossus*).
- Vulnerable: common porpoise (*Phoecoena phoecoena*), white whale (*Delphinapterus leucas*), sperm whale (*Physeter catodon*), Atlantic cod (*Gadus morhua*), tope shark (*Galeorhinus galeus*), haddock (*Melanogrammus aeglefinus*), angleshark (*Squatina squatina*) and short-snouted seahorse (*Hippoglossus hippocampus*).

3.2 Protection of marine resources by restrictions on fishing and hunting

Until 1995, pollution was the main issue at the North Sea conferences. Over the last decade, there has been an increasing awareness of the North Sea fish stocks status as well as the impact of fisheries on the ecosystem. The European Commission has published a series of sectoral action plans aiming to integrate biodiversity protection into e.g. fishery and aquaculture policies. The EU and Norway have agreed to develop harvest strategies for demersal fish stocks and for mackerel. Harvest control rules have already been implemented for herring, and the stock is currently improving.

• Nature protection

ASCOBANS (the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas) aims to coordinate and implement conservation measures for dolphins, porpoises and other toothed whales in the Baltic and North Seas. Except for a minor catch of minke whales (*Balaenoptera acutorostrata*), whales are no longer hunted.

• Resource protection

Management of North Sea fisheries is regulated within the waters of EU Member States by the EU Common Fisheries Policy (CFP). In March 2001 the European Commission published a green paper on the future of the CFP. A number of policy failings are identified and

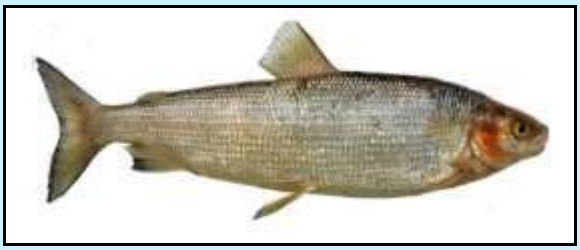
objectives for the new CFP listed. Improved conservation policy and full implementation of the biodiversity action plan for fisheries and the habitats directive are among the objectives of a framework for the new CFP. In June 2001, the Commission presented a communication to the Council and the European Parliament on a long-term recovery plan for the North Sea cod stock and other threatened fish stocks (europa.eu.int/comm/fisheries/topics/topic_en.htm).

Case study: Houting (*Coregonus oxyrhincus L.*)

In the late 1980s the population of North Sea houting in the Wadden Sea area was nearly extinct. Stockings with fingerlings in a four-year period in the larger rivers to the Wadden sea, together with general protection (i.e. no fishing) have rehabilitated the species. It is now common in the area, but still protected.

Source: www.dfu.min.dk/ffi/stockings.htm

Photo: Houting (*Coregonus oxyrhincus*)



Source: Jens Meulengracht-Madsen/Biofoto. Danmark (JMM 3861)

3.3 Research projects and monitoring programmes

There are several examples of national, international and non-governmental organisation initiatives to assess environmental quality in the North Sea area.

• The continuous plankton recorder (CPR)

The importance of obtaining regular and comparable samples of plankton over large areas of ocean led to the development in 1931 of the plankton recorder instrument; this has since been deployed from ships by most countries. The collected samples have been preserved for laboratory analysis and form the basis for many assessments.

• BioMar

The Marine Nature Conservation Review (MNCR) has, since 1987, been carrying out a survey of marine habitats and their communities on the seabed of England, Scotland and Wales. In addition, information on marine biotopes is being gathered to help identify sites of high marine conservation value. MNCR is developing a structured classification of marine biotopes for the North-East Atlantic. The classification will include all marine and brackish-water habitats that occur around the United Kingdom and Ireland and will allow for the inclusion of biotopes from other coasts of the North-East Atlantic.

• Joint assessment and monitoring programme (JAMP)

European countries bordering the North-East Atlantic have made a commitment through OSPAR to protect their marine ecosystems against adverse effects of human activities. JAMP has provided a scientific basis for identifying, prioritising and evaluating issues of concern and judging the success of remedial actions. JAMP, in cooperation with ICES, has

provided guidelines, workshops, and assessment reports for investigating biodiversity, contaminants, nutrients and the influences of offshore activities.

Other programmes

- UK Marine SACs Research Project: a five-year project for developing best management practice of marine special areas of conservation (SACs) in the United Kingdom.
- Norwegian sector: Monitoring of soft-bottom communities in connection with offshore oil production in the North Sea, at least once every third year.
- The Wadden Sea: the Trilateral Monitoring and Assessment Program (TMAP). Since 1978, the Netherlands, Germany and Denmark have coordinated their activities and measures for comprehensive protection of the Wadden Sea.
- Greenpeace initiatives for protection of the environment in the North Sea over several years (MacGarvin, 1990).
- WWF (the Worldwide Fund for Nature) is involved in numerous MPA projects, such as WWF-Germany's involvement in the Wadden Sea region.
- WWF's Endangered Seas Campaign is working to safeguard fisheries and marine biological diversity by establishing marine protected areas, reducing wasteful government subsidies that contribute to overfishing, and creating market incentives for sustainable fishing through the Marine Stewardship Council's new certification initiative.
- Marine biodiversity has been a central theme in several research projects initiated and financed by the European Union within the framework programmes. There is a concerted action called BIOMARE.

Photo: Norwegian coastal monitoring programme: Monitoring of fixed sublittoral habitats in Skagerrak by stereophotography

Source: NIVA

Bibliography

Bartsch, I., 2000. The marine macroalgae of Helgoland (North Sea): An annotated list of records between 1845 and 1999, Helgol. Mar. Res., Vol. 45, pp. 160–89.

Camphuysen, C.J., Ensor, K., Furness, R.W. *et al*., 1993. *Seabirds feeding on discards in winter in the North Sea*, NIOZ Rapport 1993–8, Netherlands Institute for Sea Research, Den Burg, Texel.

Christie, H., Fredriksen, S., and Rinde, E., 1998. *Regrowth of kelp and colonization of epiphyte and fauna community after kelp trawling at the coast of Norway*, Hydrobiologia, Vol. 375/376, pp. 49–58.

Craeymeersch, J.A., Heip, C.H.R. and Buijs, J., 1997. *Atlas of North Sea benthic fauna*, ICES Cooperative Research Report No 218.

Critchley, A.T., 1983. *Sargassum muticum: A taxonomic history including world-wide and western Pacific distributions*, J. Mar. Biol. Assoc. UK, Vol. 63, pp. 617-25.

Davidson, N.C., Laffoley, D. d'A., Doody, J.P. *et al*., 1991. *Nature conservation and estuaries in Great Britain*, Nature Conservancy Council, Peterborough.

De Jong, F., Bakker, J.F., van Berkel, C.J.M. *et al*., 1999. *Wadden Sea quality status report*, Wadden Sea Ecosystem, No 9, Common Wadden See secretariat, Trilateral Monitoring Assessment Group, Wilhelmshaven.

European Commission, 1998. *CORINE - Coastal erosion*, Office for Official Publications of the European Communities, Luxembourg, 170 pages.

Fransz, H.G., Colebrook, J.M., Gamble, J.C. et al., 1991. *The zooplankton of the North Sea*, Neth. J. Sea Res., Vol. 28, pp. 1-52.

Frid, C.L.J., Clark, R.A. and Hall, J.A., 1999. *Long-term changes in the benthos on a heavily fished ground off the NE coast of England*, Mar. Ecol. Prog. Ser., Vol. 188, pp. 13-20.

Greenstreet, S.P.R. and Hall, S.J., 1996. *Fishing and the ground-fish assemblage structure in the north-western North Sea: An analysis of long-term and spatial trends*, J. Animal Ecol., Vol. 65, pp. 577-98.

Gubbay, S., 1995. *A global representative system of marine protected areas: Volume 1. Antarctic, Arctic, Mediterranean, Northwest Atlantic, Northeast Atlantic and Baltic*, Great Barrier Reef Marine Park Authority, The World Bank, The World Conservation Union (IUCN).

Heip, C., Basford, D., Craeymeersch, J.A. *et al*., 1992. *Trends in biomass, density and diversity of North Sea macrofauna*, ICES J. Mar. Sci., Vol. 49, pp. 13-22.

Hickel, W., 1998. *Temporal variability of micro- and nanoplankton in the German Bight in relation to hydrographic structure and nutrient changes*, ICES J. Mar. Sci., Vol. 55, No 4, pp. 600-609.

Hiscock, K. (ed.), 1998. *Marine nature conservation review. Benthic marine ecosystems of Great Britain and the north-east Atlantic*, Coasts and seas of the United Kingdom, MNCR series, Joint Nature Conservation Committee, Peterborough.

ICES, 1998. *Report of the working group on the ecosystem effects of fishing activities*, ACFM/ACME: 1 Ref E, 263, International Council for the Exploration of the Seas, Committee Meeting.

ICES, 1999. *Report of the ICES advisory committee on the marine environment 1998*, International Council for the Exploration of the Seas, Cooperative Research Report, No 233.

Kaiser, M.J. and Spencer, B.E., 1996. *The effects of beam trawl disturbance on infaunal communities in different habitats*, J. Animal Ecol., Vol. 65, pp. 348-58.

Iversen, S.A. (ed.), 2001. *Havets resurser 2001*, Fisken og havet, No 1-2001, Institute for Marine Research, Bergen.

Kerry, J., Coyne, R., Gilroy, D. et al., 1996. *Spatial distribution of oxytetracycline and elevated frequencies of oxytetracycline resistant bacteria in the sediments beneath a salmon farm following oxytetracycline therapy*, Aquacult., Vol. 145, pp. 31-9.

Knijn, R.J., Boon, T.W., Heessen, H.J.L. *et al*., 1993. *Atlas of North Sea fishes*, ICES Cooperative Research Report, No 194.

Künitzer, A., Basford, D., Craeymeersch, J.A. et al., 1992. *The benthic infauna of the North Sea: Species distribution and assemblages*, ICES J. Mar. Sci., Vol. 49, pp. 127-143.

Law, R. and Rowell, C.A., 1993. *Cohort-structured populations, selection responses, and exploitation of the North Sea cod*, in The exploitation of evolving resources (T.K Stokes).

Lindeboom, H.J. and de Groot, S.J., 1998. *IMPACT-II: The effects of different types of fisheries on the North Sea and Irish Sea benthic Ecosystems*, NIOZ Rapport 1998-1, Den Burg.

MacGarvin, M., 1990. *Greenpeace - The seas of Europe - The North Sea, Collins and Brown Ltd, 140 pages.*

Nehring, S., 1999. *Impacts of tributylitin (TBT) from anti-fouling pains on snail populations on the German North Sea coast*, Hydrologie und Wasserbewirtschaftung, Vol. 43, No 2, pp. 66-74.

O'Brien, C.M., Fox, C.J., Planque, B. *et al*., 2000. *Climate variability and North Sea cod*, Nature, Vol. 404, p. 142.

OSPAR, 2000. *Quality Status Report 2000, Region II - Greater North Sea*. OSPAR Commission, London, 136 pages.

Pearson, T., and Mannvik, H.P., 1998. *Long-term changes in the diversity and faunal structure of benthic communities in the northern North Sea: Natural variability or induced instability?* Hydrobiologia, Vol. 375/376, pp. 317-329.

Picton, B.E. and Costello, M.J., 1998. *The BioMar biotope viewer: A guide to marine habitats, fauna and flora in Britain and Ireland*, Environmental Sciences Unit, Trinity College, Dublin.

Raffaelli, D., 2000. *Interactions between macro-algal mats and invertebrates in the Ythan estuary, Aberdeenshire, Scotland*, Helgol. Mar. Ser., Vol. 54, pp. 71-9.

Reise, K., Gollasch, S. and Wolff, W.J., 1999. *Introduced marine species of the North Sea coasts*. Helgol. Meeresunters., vol. 52, no. 3-4, pp. 219-234.

Rijnsdorp, A.D., van Leeuwen, P.I., Daan, N. *et al*996. *Changes in abundance of demersal fish species in the North Sea between 1906-1909 and 1990-1995*, ICES J. Mar. Sci., Vol. 53, pp. 1054-62.

Rogers, S.I., Rijnsdorp, A.D., Damm, U. and Vanhee, W., 1998. *Demersal fish populations in the coastal waters of the UK and continental NW Europe from beam trawl survey data collected from 1990 to 1995*, J. Sea Res., Vol. 39, pp. 79-102.

Rygg, B., 1985. *Effect of sediment copper on benthic fauna*, Mar. Ecol. Prog. Ser., Vol. 25, pp. 83-9.

SFT, 1997. *Discharges of oil and chemicals on the Norwegian continental shelf 1996*, SFT-report 97-23, TA-no. 1470/1997, Norwegian State Pollution Control Authorities, Oslo.

Skjoldal, H.R. and Dundas, I. (eds), 1991. *The Chrysocromulina polylepis bloom in the Skagerrak and in the Kattegat in May-June 1988*: Environmental conditions, possible causes and effects, ICES Cooperative Research Report, No 175.

Svelle, M., Aarefjord, H., Heir, H.T. *et al*., 1997. *Intermediate Ministerial Meeting on the Integration of Fisheries and Environmental Issues, 13-14 March 1997*, IMM97, Bergen.

Svendsen, E., Aglen, A., Iversen, S. A. *et al*., 1995. *Influence of climate on recruitment and migration of fish stocks in the North Sea*, pp. 641-53, in Climate change and northern fish populations (edited by R.J. Beamish), Can. Spec. Publ. Fish. Aquat. Sci., Vol. 121.

Tunberg, B.G. and Nelson, W.G., 1998. *Do climatic oscillations influence cyclical patterns of soft bottom macrobenthic communities on the Swedish west coast?* Mar. Ecol. Prog. Ser., Vol. 170, pp. 85-94.

Warwick, R.M. and Clarke, K.R., 1993. *Increased variability as a symptom of stress in marine communities*, J. Exp. Mar. Biol. Ecol., Vol. 172, Nos 1-2, pp. 215-26.

Ærtebjerg, G., Carstensen, J., Casartelli, S. et al., 2001. *Eutrophication in Europe's coastal waters*, EEA Topic Report 7/2001.