6 North Sea

6.1 Ecosystem overview

6.1.1 Ecosystem components

Seabed topography and substrates

The topography of the North Sea can be broadly described as having a shallow (<50 m) southeastern part, which is sharply separated by the Dogger Bank from a much deeper (50–100 m) central part that runs north along the British coast. The central northern part of the shelf gradually slopes down to 200 m before reaching the shelf edge. Another main feature is the Norwegian Trench running east along the Norwegian coast into the Skagerrak with depths up to 500 m. Further to the east, the Norwegian Trench ends abruptly, and the Kattegat is of depths similar to the main part of the North Sea (Figure 6.1.1).

The substrates are dominated by sands in the southern and coastal regions and fine muds in deeper and more central parts (Figure 6.1.2). Sands become generally coarser to the east and west, with patches of gravel and stones existing as well. In the shallow southern part, concentrations of boulders may be found locally, originating from transport by glaciers during the ice ages. This specific hard-bottom habitat has become scarcer, because boulders caught in beam trawls are often brought ashore. The area around, and to the west of the Orkney/Shetland archipelago is dominated by coarse sand and gravel. The deep areas of the Norwegian Trench are covered with extensive layers of fine muds, while some of the slopes have rocky bottoms. Several underwater canyons extend further towards the coasts of Norway and Sweden.

A number of sand banks across the North Sea qualify for protection under the EU habitats directive, mainly along the UK coast, eastern Channel, the approaches to the Skagerrak, and the Dogger Bank. Extensive biogenic reefs of Lophelia have recently been mapped along the Norwegian coastline in the eastern Skagerrak, while Sabellaria reefs have been reported in the south, although their distribution and extent is not known. Gravels also qualify for protection, but comprehensive maps at a total North Sea scale are not readily available.

Figure 6.1.1 Bathymetry of the North Sea (source RIVO – alternative from ICES).
Circulation patterns

Circulation in the North Sea is classically presented as an anticlockwise gyre driven mainly by wind forcing. However, empirical observations as well as modeling results indicate that the pattern may be reversed temporally as a result of wind forcing, or split into two separate gyres in the north and south. Circulation may even cease for limited times (Kauker and von Storch, 2000). Such changes and their timings may be important for specific life history stages of various species because they can, for instance, affect the transport of eggs and larvae to specific nursery areas or feeding conditions.

The main inflow is of relatively warm (at least during winter) and more saline North Atlantic water along the shelf break into the Norwegian Trench, and also around the Shetland and Orkney Islands. Changes in zooplankton and fish distributions have been linked to the strength of these inflows. Atlantic water also enters into the southern North Sea, via the Channel (Hughes and Lavin, 2004). The Kattegat and eastern Skagerrak are strongly influenced by brackish surface water entering from the Baltic, following the Swedish coast and turning west along southern Norway. However, the bottom-water layer is of oceanic origin and runs below the brackish water layer in the opposite direction. Residence time of North Sea water is estimated to be in the order of one year. The general circulation pattern is shown in Figure 6.1.3.

Figure 6.1.2. Seabed sediment types of the North Sea. http://www.awi-bremerhaven.de/GEO/Marine_GIS/Margis%20homepage/index.html.
A number of frontal systems exist (e.g. Fair Isle, Flamborough, the Frisian front, and Skagerrak), but they vary considerably in time and space depending on windforcing, current strength, and the physical properties of the different water masses. Tidal currents are strong in the southern North Sea, especially in the coastal regions.

**Physical and chemical oceanography**

North Sea oceanographic conditions are mainly determined by the inflow of saline Atlantic water through the northern entrances and, to a lesser degree, through the Channel. These waters mix with river run-off in coastal regions and the lower-salinity Baltic outflow through the Kattegat. The temperature of surface waters is largely controlled by local solar heating and atmospheric heat exchange, while temperature in the deeper waters of the northern North Sea is influenced largely by the inflow of Atlantic water. Figure 6.1.4. shows average bottom temperatures in winter and summer for 1997–2002.
The salinity and the temperature variations generally reflect the influence of the North Atlantic Oscillation (NAO) on the movement of Atlantic water into the North Sea and the ocean–atmosphere heat exchange. Numerical model simulations show strong differences in the circulation depending on the state of the NAO. A balance of tidal mixing and local heating force the development of a seasonal stratification from April/May to September in most parts of the North Sea (e.g. Sharples et al., 2006). This stratification is absent in the shallower waters of the southern North Sea throughout summer. The extent and duration of this mixed area is probably an important environmental factor for fish in this area.

Results presented in ICES (2007) show that area-averaged sea surface temperatures of the North Sea have been increasing since June 2001 (Figures 6.1.5 and 6.1.6). The vegetation period (primary production) was much longer than usual in 2006. The Helgoland Roads standard station demonstrates that, since the cold winter of 1996, sea surface temperature has been above the 30-year mean (1971–2000), with positive anomalies of 0.5–1.0°C. In 2006, March and April revealed negative anomalies up to −1°C, but positive anomalies exceeded 1°C continuously from June to December, with maximum anomalies of 2.7°C in October and 2.3°C in December.

Figure 6.1.5     Southern North Sea. Annual mean surface temperature anomaly at Station Helgoland Roads.

Figure 6.1.6     Northern North Sea. Temperature anomaly in the Fair Isle current entering the North Sea from the North Atlantic.

The warm conditions in the North Sea that had lasted since summer 2006, continued in the second quarter of 2007. The temperature anomalies in the first quarter were positive by 0–1°C in the northern North Sea and by 2–4°C in the southeastern part. These high positive anomalies persisted in April but were somewhat reduced to 1–2°C in the southeastern area in June. Seasonal stratification started in April in the waters west of Denmark and by May the waters north of the Dogger Bank were markedly stratified. SST data from the 1st quarter IBTS 2007 survey are presented in Figure 6.1.7.
The continued and significant increase in seawater temperatures was also observed at Arendal on the Norwegian Skagerrak coast (ICES, 2007b). Daily recordings of sea surface temperatures at Arendal from January 2006 to December 2006 are shown in Figure 6.1.8. The temperature during the 4th quarter in 2006 remained above average, most of the time about 2 SD above the long-term average (climatology). This situation continued during the 1st quarter in 2007, with sea surface temperatures 1.5–2 SD above the long-term average in January and March. This was interspersed by a cooling of the sea surface to close to average conditions in late February.

Surface salinity also rose in the recent years but from a recent low value to close to the long-term average. Near-bottom salinity in the northwestern North Sea has been above average the past three years, but last year it dropped compared to the record high value observed in 2005 (Figure 6.1.9).
Figure 6.1.9 Near-bottom salinity in the northwestern part of the North Sea in the summers of 1970–2006.

There is considerable eutrophication in some areas of the North Sea, particularly in the Wadden Sea area, the southern part of the Kattegat and coastal part of the Skagerrak, as well as in shallow waters and estuaries along the UK and European mainland coast. Below the halocline, decomposition of organic matter has occasionally caused oxygen deficiency during late summer/autumn. This phenomenon is linked to enhanced primary productivity but may locally be a natural process, especially in enclosed inshore areas such as the Kattegat, fjords, and estuaries. However, oxygen deficiency is accelerated by large-scale eutrophication (Karlsson et al., 2002).

See also the general text on major climatic and oceanographic features in a separate section on the Northeast Atlantic.

Major climatic and ecosystem features

The water circulation through the North Sea is generally anticlockwise, with most of the water entering in the north over the North Sea plateau and exiting through the Norwegian Trench along the coast of Norway. The inflow of Atlantic water shows large seasonal and interannual variability, driven by winds and pressure gradients along the continental slope (Pingree, 2005) which vary from year to year. This is known as the North Atlantic Oscillation (NAO). The NAO winter index, which is a measure of the air pressure gradient between the Azores High and the Iceland Low, has undergone both long-term and short-term fluctuations. High or positive NAO index conditions typically drive a strong inflow and transport through the North Sea, while weaker flows are associated with negative NAO anomalies (Reid et al., 2003). The index decreased through the mid-part of the last century to a minimum in the 1960s. This coincided with the “Great salinity anomaly” which was a signal of low salinity water that propagated around the subarctic gyres of the northern North Atlantic (Dickson et al., 1988; Blindheim and Skjoldal, 1993). The anomaly arrived in the North Sea in the late 1970s, manifested as pronounced minima in salinity and temperature and subsequently the NAO index shifted to high values from the late 1980s through the first part of the 1990s, followed by a marked drop to a strong negative anomaly in winter 1995/96. These were very marked climatic events that have been associated with changes in plankton composition (Planque and Batten, 2000; Beaugrand et al., 2002; Beaugrand, 2003; Reid et al., 2003), fish populations, and other biota in the North Sea (Reid and Edwards, 2001; Reid et al., 2001; Edwards et al., 2002; Reid and Beaugrand, 2002).

Modelled inflow of water (Skogen and Søiland, 1998) into the North Sea through the northern boundary between the Orkneys, Shetland, and the western coast of Norway during the 1st quarter of the year, was low in the late 1960s and late 1970s, while increasing substantially in the late 1980s and early 1990s (Figure 6.1.10), corresponding to the low and high NAO index situations described above. These changes in flows have been related to changes in plankton abundance and composition in the North Sea, being characterized as cold-biological and warm-biological events (Reid et al., 2003), and also to the variance in recruitment or distribution of the five major North Sea fish populations having available data for the period 1971–1991 (Svendsen et al., 1995). Climate forcing was thought to be the most likely explanation for the “gadoid outburst” in the 1960s, which was a period with favorable recruitment conditions for several of the gadoid groundfish species in the North Sea (Cushing, 1984). Although significant environmental events have had an impact on the status of the North Sea ecosystem, including its fishery, time-series data on the spawning-stock biomass (SSB) of six important demersal fish stocks (ICES, 2007) reveals considerable variation (Figure 6.1.11), reflecting the combined influence of the environment and impact from fishing. North Sea haddock, cod, and saithe were at high biomass levels in the late 1960s and early 1970s (the gadoid outburst) followed by subsequent declines to low levels in the early 1990s. Haddock and saithe have since recovered whereas the decline of cod has continued. Fishing pressure (fishing mortality) in the 1990s was so high that the stock was predicted to collapse based upon theoretical considerations (Cook et al., 1997). The warm climate and low zooplankton abundance (particularly of *Calanus finmarchicus*) have also been implied in the decline, and lack of recovery, of North Sea cod (Planque and Frédou, 1999; Beaugrand et al., 2003; Drinkwater, 2005; Rindorf and Lewy, 2006).
Pelagic, plankton-feeding fish are another important component of the North Sea ecosystem. Because of overfishing, North Sea herring declined to a very low level in the 1970s (Figure 6.1.12), but subsequent recovery efforts have allowed the stock to increase to a level within safe limits. North Sea mackerel stocks were also fished to unsafe levels in the 1970s and the North Sea stocks of these have not recovered. However, mackerel from the Western stock (in the NE Atlantic) is abundant and uses the northern North Sea as part of its feeding area. Other important pelagic fish species in the North Sea ecosystem are sprat, sandeel, and blue whiting.

Pelagic fish are likely to exert pressure on the plankton which constitutes their food, as seen by observations in the Barents Sea ecosystem (Skjoldal and Rey, 1989; Dalpadado and Skjoldal, 1996) and the North Sea (Reid et al., 2000). *Calanus finmarchicus* (a cold-water artic-boreal species of copepod) has fluctuated inversely with *Calanus helgolandicus* (a warm-water temperate species of copepod), being abundant under negative NAO index conditions. The strong inverse correlation between *C. finmarchicus* and *C. helgolandicus* broke down after 1995, presumably reflecting less *Calanus finmarchicus* in the inflowing water originating in the Norwegian Sea (Planque and Reid, 1998; Reid et al., 2003), and possibly increased predation pressures arising from increased pelagic fish stocks and their resumed migration to feed in the Norwegian Sea (Holst et al., 2004).

In addition, recruitment conditions for blue whiting were exceptionally good for several years starting in 1995, leading to a marked increase in the stock of young fish feeding in the Norwegian Sea (Monstad, 2004; Skjoldal and Sætre, 2004). It has been suggested that predation by these two very large pelagic fish stocks, herring and blue whiting (each producing between 5 and 10 million tonnes of fish landings each year) could have lowered the amount of *Calanus*, thereby indirectly influencing the adjacent North Sea ecosystem (Skjoldal and Sætre, 2004).

![North Sea Flux (Q1)](image)

**Figure 6.1.10** The annual Q1 average net flux of seawater across two boundaries into the northern North Sea, namely the Orkney/Shetland transect and the Faroe/Shetland transect. Both show a large negative flux in 1989, which is associated with a step increase in the North Sea temperature as the amount of cold deep water entering from the Northeast Atlantic was particularly low at this time (Skogen and Søiland, 1998).
Effects of climate on zooplankton and their consequences for marine foodwebs are clear. Beaugrand et al. (2003) showed from CPR data and cod catch data in the North Sea that a decreasing abundance of *Calanus finmarchicus* and a concomitant shift towards the warmer water species *Calanus helgolandicus* was clearly associated with a reduction in cod recruitment. This study demonstrated the critical importance of zooplankton in the marine foodweb, fishery yields, and their sensitivity to climate change. Likewise, Corten (2000) showed that the distribution of herring depends on the persistence of suitable food organisms, in particular abundance of *Calanus finmarchicus*. Using PCA, Beaugrand et al. (2003) found strong relationships between NAO, SST, phytoplankton, *Calanus finmarchicus*, and salmon. Sims and Reid (2002) found parallel declines in *Calanus* and basking sharks. Seabirds are strongly impacted by the abundance of sandeels, which in turn is determined by the abundance of zooplankton and phytoplankton (Frederiksen et al., 2006).

Planque and Fromentin (1996) found a strong relationship between *Calanus finmarchicus* and NAO from 1958 to 1995, but the correlation was not as strong after 1996 (Planque and Reid, 1998; Pershing et al., 2004). Beaugrand et al. (2002)
found a decrease in the abundance of cold water and Arctic zooplankton species and an increase in warmer water ones in the Northeast Atlantic and the North Sea.

In analysing CPR data from the North Sea between 1960 and 2003, Hays et al. (2005) observed a clear decrease in the abundance of *Calanus finmarchicus*, and an increase in *C. helgolandicus*, with a marked overall decrease in both species combined. Over the whole Northeast Atlantic, Edwards et al. (2006) found a distinct decrease in copepod abundance from 1946 to 2004. In addition to copepods, phenological studies of invertebrate larvae (decapods and echinoderms) in the North Sea reveal a clear trend towards earlier seasonal peaks in abundance, indicating the effects of a warming environment. There have also been clear shifts in community structure in the North Sea, from a low-diversity boreal community during the late 1970s to a higher-diversity warmer water community during the 1990s to the present.

The spring bloom in the Southern Bight and the Channel occurred somewhat later in 2007 than in the two preceding years, and vigorous blooms with high chlorophyll content developed in coastal waters in April and May. On the Norwegian Skagerrak coast the spring bloom occurred in late March, which is later than usual. Chlorophyll levels were low in May and June. Based on satellite-observations of chlorophyll, the spring bloom started first (March) in the stratified waters of Kattegat and Skagerrak and in the clear waters of the Dogger Bank, and latest (May–June) in the northwestern part of the North Sea and in the western Channel.

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**Figure 6.1.13** A simple ratio between a warm-water species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) per month from 1958 to 2005. Red values indicate a dominance of the warm-water species and blue values the dominance of the cold-water species. (0 = total *C. finmarchicus* dominance, 1 = total *C. helgolandicus* dominance). Data from North Sea (Edwards et al., 2007).

**Benthos and larger invertebrates**

The 50 m, 100 m, and 200 m depth contours broadly define the boundaries between the main benthic communities in the North Sea, with local community structure further modified by sediment type (Künitzer et al., 1992; Callaway et al., 2002). Descriptions of the spatial distribution of infaunal and epifaunal invertebrates show that the diversity of infauna and epifauna is lower in the southern North Sea than in the central and northern North Sea. However, large-scale spatial gradients in biomass are less pronounced. Bottom temperature, sediment type, and trawling intensity have been identified as the main environmental variables affecting community structure. Epifaunal communities are dominated by free-living species in the south and sessile species in the north.

Reliable information on trends in biomass of benthic species is largely lacking. Although there is a large body of evidence that towed bottom gears kill off large quantities of benthic animals and direct effects are undoubtedly large (Collie et al., 2000; Kaiser et al., 2006), the long-term impact is unknown.

Large-scale discarding of a variety of macrobenthos species occurs in the mixed demersal trawl fisheries, particularly in the beam trawl fishery for sole and plaice and the otter trawl fishery for Norway lobsters. These fisheries alter the biomass, production, size structure, and diversity of benthic communities, with the intensity and patchiness determining the aggregate impacts (Kaiser et al. 2000). In areas with periodical oxygen deficiency, e.g. in the Kattegat, the benthic fauna is affected by mortality or reduced growth (Diaz and Rosenberg, 1995). This may in turn cause shortage of food for demersal fish.

Directed fisheries exist for the benthic invertebrate species *Nephrops norvegicus*, *Pandalus borealis*, and brown shrimp *Crangon crangon*.

It was concluded in ICES (2006a) that in general the spatial distribution of the macrofaunal communities in 2000 was rather similar to that in 1986, as described by Künitzer et al. (1992). The decrease in total abundance found in the
northern North Sea (>100 m) was influenced by the use of different mesh sizes in 1986 (0.5 mm) and 2000 (1 mm) as well as by the spatial resolution of the station grid. The increase in species number in this region in 2000 might be the result of improved taxonomic precision. “Real” changes in community structure between 1986 and 2000 can thus be more confidently discussed for the southern North Sea. Changes in community structure north of the 50 m depth contour may be related to changes in the hydroclimate caused especially by changes in the North Atlantic Oscillation (NAO) which, in positive mode, results in an increase in SST, changes in sediment structure, and in food availability, as described by Reid and Edwards (2001) and Kröncke et al. (1998). Wieking and Kröncke (2001) described the NAO-influenced changes in hydrography, especially north and south of the Dogger Bank. The increased inflow of Atlantic water masses through the Fair Isle channel strengthened the frontal system north of the bank, creating a “strong” border between northern and southern water masses. High current velocities in the northern part of the Dogger Bank (Siegismund and Schrum, 2001) in addition to a seasonal jet (Brown et al., 1999), limit the accumulation of particulate organic material in seabed sediments. Klein et al. (1999) showed that, during storms, fine sediments at the seabed are mobilized at depths of up to 60 m at the northern slope of the Dogger Bank. Thus, the decrease in total species number and the increase in species such as the small polychaete Paramphinome jeffreysii, as well as the dominance of the interface-feeding polychaetes Myriochele spp. and Spiophanes bombyx north of the 50 m depth contour, provide supporting evidence of a change in hydrodynamics affecting sediment structure and stability, as confirmed by changes in the median grain size in this area associated with changes in food availability (Wiek ing and Kröncke, 2001). Since P. jeffreysii and Myriochele spp. are considered to be cold-temperate species, their increase in abundance north of the 50 m depth contour might be a hint of colder northern water masses north of the frontal system. Changes observed in the communities at the offshore stations in the southwestern North Sea towards the English Channel and the eastern part of the Frisian Front indicate similar environmental influences. The decrease in the polychaete Ophelia borealis in these regions might be influenced by an increase in SST (O. borealis is a cold-temperate species) as well as by changes in the sediment composition as found by Wiek ing and Kröncke (2001) at the Dogger Bank. However, there was no evidence of a systematic change in sediment particle sizes between the 1986 and 2000 surveys. At the coastal stations in the southwestern North Sea towards the English Channel and at the western part of the Frisian Front, an increase in interface-feeding polychaetes such as S. bombyx, Magelona spp., and Lanice conchilega, as well as the bivalve Spisula spp., might be caused by greater food availability at the Flamborough and Frisian Fronts owing to an NAO-induced increase in SST and hydrodynamic forces. Owing to frontal conditions and enhanced primary production, food supply to the benthos (quality and quantity) will be higher than in non-frontal areas at comparable depths. In the eastern North Sea in 2000, the increase in phoronids and other interface-feeding species such as the polychaete S. bombyx and the bivalves Fabulina fabula and Corbula gibba also indicate an NAO-induced increase in food availability owing to higher primary production in the German Bight, as described by Reid et al. (1998) and Reid and Edwards (2001). Current-induced changes in the sediment structure might have caused the increase in the brittlestar Amphiura brachiata and the sea urchin Echinocyamus pusillus, which prefers coarser sediments, but A. brachiata is also a warm-temperate species (Wiek ing and Kröncke, 2001)

Fish community

Dominant species

Estimates of the total biomass of North Sea fish in the 1980s were in the order of 12 million tonnes, approximately 67% of which consisted of the major eleven exploited species (Daan et al., 1990). Throughout the year, the pelagic component is dominated by herring Clupea harengus. Mackerel Scomber scombrus and horse mackerel Trachurus trachurus are mainly present in summer when they enter the area from the south and from the northwest. Dominating gadoid species are cod Gadus morhua, haddock Melanogrammus aeglefinus, whiting Merlangius merlangus, and saithe Pollachius virens, whereas the main flatfish species are common dab Limanda limanda, plaice Pleuronectes platessa, long rough dab Hippoglossoides platessoides, lemon sole Microstomus kitt, and sole Solea vulgaris. The major forage fish species are sandeels Ammodytes marinus, Norway pout Trisopterus esmarki, and sprat Sprattus sprattus, but juvenile herring and gadoids also represent an important part of the forage stock. However, large annual variations in species composition occur as a consequence of natural fluctuations in the recruitment success of individual species.

The late 1960s up to the early 1980s were characterized by a sudden increase in the abundance of large, commercially important gadoid species: the ‘gadoid outburst’. During this period, cod, haddock, whiting, and saithe all produced a series of strong year classes. These gadoid stocks of have been decreasing since then, with cod especially being at the lowest level observed over the last century. North Sea herring and mackerel were heavily overfished in the 1960s and 1970s and the stocks collapsed. The herring stock has recovered following a closure of the fishery in the late 1970s. The North Sea mackerel stock has remained low. During the second half of the year North Sea mackerel mix with the Northeast Atlantic mackerel stock; both stocks are thus affected by the fishery for mackerel.

Over the last decade a number of so-called ‘southern’ species have increased, which is probably a response to the increased water temperatures (Beare et al., 2004). However, many ‘northern’ species have also increased, although less markedly (Daan, pers. comm.).
**Size spectrum**

Absolute numbers of both small fish belonging to all species and of demersal species with a low maximum length have steadily and significantly increased over large parts of the area during the past 30 years, and the abundance of large fish has decreased (Daan et al., 2005). For comparison along the Swedish Skagerrak coast see Svedäng (2003). The best available explanation for this is the reduction of the predation pressure on juvenile fish and on species that remain small. This is an indirect effect of overexploitation of the large predatory fish species.

**Species richness**

Species richness in the North Sea is highest around the edges (particularly in Scottish waters, in the Southern Bight, and in the Kattegat) and lowest in the central North Sea (Figure 6.1.14). The edge areas are frequently invaded by species from adjacent areas that are atypical of the North Sea. Based on the IBTS surveys in February, species richness appears to have increased steadily over the past 30 years (Figure 6.1.15) and trends have been roughly comparable for northerly and southerly species. Other studies have reported negative trends in species richness, particularly in heavily fished areas in the northern North Sea (Greenstreet and Rogers, 2006). Apparent species richness signals may be dependent on the survey gear used, the time of year, and the area in which data were collected.

![Spatial indices of species richness for all species in the North Sea.](image)

**Figure 6.1.14** Spatial indices of species richness for all species in the North Sea.

![Species richness based on IBTS surveys.](image)

**Figure 6.1.15** Species richness based on IBTS surveys.
The principal effects of fishing on the size and species composition of the fish community have been a drop in the mean size of individuals in the community concomitant with an increase in mortality, resulting in species with larger body sizes forming a smaller proportion of the community biomass (Gislason and Sinclair, 2000; Jennings et al., 1999). This is reflected in the slopes of size spectra becoming steeper (Rice and Gislason, 1996), reductions in the abundance of large species with low intrinsic rates of increase, such as many elasmobranchs (Walker and Heessen, 1996; Walker and Hislop, 1998), and increases in the abundance of many smaller species (Greenstreet and Hall, 1996; Heessen and Daan, 1996; Greenstreet et al., 1999).

Biomass/abundance of crucial species in the food chain

Landings of Norway pout in recent years were the lowest of the past two decades. The spawning biomass of sandeel has declined throughout the past 15 years and is at a low level (ICES, 2007). Sandeels are an essential component of the diet of most piscivorous fish species (Daan et al., 1989; Hislop et al., 1997; Greenstreet et al., 1997) as well as birds (Tasker and Furness, 1996; Wanless et al., 1998) and marine mammals (Hammond and Grellier, 2006; Santos et al., 2004), and their low abundance is therefore expected to have severe implications for the whole North Sea ecosystem.

Status of vulnerable species

Certain highly migratory species that have been fairly common historically in the North Sea have disappeared completely (e.g. tuna) or have become very rare (e.g. halibut Hippoglossus hippoglossus). Recently species like hake Merluccius merluccius and pollack Pollachius pollachius in the Skagerrak and Kattegat are decreasing. The stocks of most elasmobranchs are at low levels. The spurdog (Squalus acanthias) was the most common shark species but is now considered to be depleted to approximately 5% of its virgin biomass in the whole Northeast Atlantic (Hammond and Ellis, 2005). Species as porbeagle and tope have become rare. Most ray species are at low levels and have disappeared from large parts of the North Sea (Walker and Heessen, 1996). Spatial management measures have been proposed, and in some cases implemented to protect the remaining stocks.

Fish population structure

Recent tagging studies suggest that the Skagerrak coast and the Kattegat may function as nursery areas for North Sea cod, and that return migration to the North Sea is common (Svedäng et al., 2007). The existence of separate subpopulations in the Kattegat in relation to putative subpopulations in the Skagerrak and the North Sea has also been further corroborated by genetic surveys, supporting the proposition of a spatially segregated stock structure in the eastern North Sea region (Carl André, pers. comm.). Due to the disappearance of local spawning subpopulations of cod in the past 20 years, the North Sea spawning stock has become increasingly more important for the recruitment of cod in the Kattegat–Skagerrak area (Svedäng, 2003; Cardinale and Svedäng, 2004). However, remnants of the collapsed Kattegat population (ICES, 2007) still spawn in the southeastern Kattegat (Vitale et al., in press).

Demersal elasmobranchs

In the North Sea about 10 skate and ray species occur as well as seven demersal shark species. Thornback ray R. clavata is probably the most important ray for the commercial fisheries. Preliminary assessments for this species were presented in ICES (2005). The trends in total international landings of rays and skates for Area IV are shown in Figure 6.1.16 (ICES, 2007).
Demersal elasmobranchs in the North Sea, Skagerrak, Kattegat, and eastern Channel: total international landings of rays and skates from Areas IV and I & II, and EC TAC for the North Sea.

*Raja clavata* is restricted mainly to the southwestern part of the North Sea. Survey indices of abundance increased during the 1980s, followed by a decline to the mid-1990s, and with a recent increase (Figure 3.8.17). The manner in which the total area occupied (AO) changed over time, fluctuating but being lower after the mid-1990s, bore little resemblance to the pattern of abundance. Most of the abundance is concentrated in a small area to the southwest of the survey area. The present total AO is only 44% of the extent of the species in the 1980s.

All four skate species appear to have maintained or increased their abundance since 1980. However, for at least two species, the area occupied (AO) has varied in a manner quite different from changes in abundance. In all cases high-density AO (at the centre of the mass) corresponded more closely to the observed abundance changes. Total AO, reflecting the extent of the distribution of a species is often used as a measure of population status. However, it is clear from this comparison of spatial dynamics in relation to changes in abundance of four species of skates in the North Sea that total AO may be misleading. Total AO may not reflect population changes and therefore should be used with caution when being used to assess the status of species. A clear example of this is the large decline in total AO of *R. clavata*, which did not match the changes in abundance. *R. clavata* has become more concentrated at the centre of the mass. This type of pattern should therefore be regarded with caution, particularly if the species becomes more concentrated where fishing effort is high.
**Birds**

About 2.5 million pairs of seabirds breed around the coasts of the North Sea, belonging to some 28 species. While most species breed in dense colonies along the coast, they make very different use of the marine ecosystem. During the breeding season, some species depend on local feeding conditions within tens of kilometres around their colony, whereas others may cover several hundreds of kilometres during their foraging trips. Outside the breeding season, some species stay quite close to their breeding grounds whereas others migrate across the North Sea or elsewhere, even as far as the Antarctic. Feeding habits also diverge. Auks and cormorants dive from the surface, gannets and terns use plunge diving, and gulls feed mostly from the surface. A few (especially skuas) are kleptoparasites (Dunnet et al., 1990). Their food resources vary accordingly, ranging from plankton to small schooling fish and discards. Because of all these differences, seabirds do not represent a single homogeneous group that responds to fisheries in some uniform way. A few species profit directly from human consumption fisheries, either discards or offal, e.g. fulmars and gulls.

Current seasonal distributions, status, and trends of these species are well known and documented in ICES (2003). Many have shown a marked increasing trend over the last century. Historically, auks and cormorants have been hunted, but are now protected in some areas (e.g. southern North Sea and Kattegat). Gull numbers have been controlled in many areas. Fulmars may have benefited from expansion in fishing. Skuas may have profited directly from the increase in population size of seabirds in general. On a shorter time-scale, 12 out of 28 species show an increasing trend during the last decade and four a decreasing trend, while four appear to be stable and for another four the situation is unknown. Local breeding success of some species has been low in some recent years. This been related to a local shortage of forage fish. Although the industrial sandeel fishery has been blamed by some for this failure, there is only limited evidence to support this. The current view is that natural (or maybe climate-change induced) variation in sandeel recruitment is largely responsible. Nevertheless, industrial fishing at these times does not improve the situation and various restrictions have been implemented.

ICES has recommended that trends in breeding success within individual colonies of black-legged kittiwakes *Rissa tridactyla* might serve as an index of the quality of local feeding conditions within the framework of Ecological Quality Objectives (EcoQO) proposed by OSPAR (ICES, 2003).

**Mammals**

Many cetacean and pinniped species have been observed within the North Sea, but most of these must be considered vagrants and only a few constitute resident representatives of the North Sea ecosystem.

Harbour *Phoca vitulina* and grey *Halichoerus grypus* seals have gone through large population changes over the past century. Both species typically inhabit coastal habitats, because they need haul-out sites for pupping and weaning. However, they make extensive foraging trips into the open sea (grey seals in particular). Because of extensive hunting, followed by reduced reproduction rates owing to effects of contamination, the populations of harbour seals along the continental coast reached an all-time low in the 1970s. Subsequently, these populations have increased steadily at an annual rate of 4%, with two major interruptions in 1988 and 2002, when the populations were hit by outbreaks of the phocine distemper virus. The numbers of harbour seals at Orkney, Shetland, and the Scottish North Sea coast have continued to decline since the phocine distemper virus (PDV) outbreak in 2002. This is in contrast to the situation following the 1988 outbreak, and in contrast to the harbour seals in other UK areas and in the southeastern North Sea. The reasons for the decline are not clear at present. Grey seals occur predominantly along the British coast and have been increasing also. In recent years, new colonies have been founded along the continental coast as well. Seals interact with various fishing operations, because they may feed on fish caught in passive gear, but also because they may be caught in various gears. Estimates of annual consumption by grey seals increased substantially between 1985 and 2002 in line with the almost threefold increase in the grey seal population size. Estimated annual prey consumption was 49 000 t in 1985 and 161 000 t in 2002. In 2002 grey seals in the North Sea consumed mainly sandeel (69 000 t), cod (8300 t), haddock (6500 t), and plaice (5200 t), but also commercial species such as whiting, saithe, ling, and herring were taken. Of non-commercially exploited fish, there were large increases since 1985 in the estimated consumption of sea-scorpions (6600 t) and dragonets (1900 t). Scottish fishers claim that the increasing grey seal population, rather than their own activities, is responsible for the reduced availability of commercial fish species, and they advocate the culling of seals.

Although several cetacean species visit the North Sea, the dominating species are minke whales, harbour porpoises, and whitebeaked dolphins. Population estimates derived from surveys made in 1994 are available for harbour porpoise *Phocoena phocoena* (about 340 000), white-beaked dolphin *Lagenorhynchus albirostris* (7900), and minke whale *Balaenoptera acutorostrata* (7300). Preliminary abundance estimates from a survey conducted in 2005 indicate *status quo* for all these species. Harbour porpoises, however, have shifted their focal distribution from the northern part of the North Sea to the southern part. Minke whales and whitebeaked dolphins have overlapping distributions and are mainly found in the northern part of the North Sea. In terms of biomass, the minke whale is the most important marine mammal occurring and consumes small fish such as sandeel. Harbour porpoise is the second most important from a biomass...
perspective, and the North Sea may represent the most important habitat for this species on the planet. A small resident population (approximately 130 individuals) of bottlenose dolphins *Tursiops truncatus* is located off the east coast of Scotland.

The main concern about interactions with human activities is the bycatch in fishing operations and effects of contaminants. Specifically, the large bycatch of harbour porpoise in gillnet fisheries has led to management measures.

**Porpoise**

The harbour porpoise is the most commonly encountered and widely distributed cetacean species in the North Sea but there are few sightings south of 47°N. Overall abundance of harbour porpoises in the North Sea and adjacent areas has not changed between the two SCANS surveys (1994 and 2005). Harbour porpoise numbers in the whole area were estimated to be 386,000 (coefficient of variation, CV=0.20). Porpoise density was lowest in strata along the outer shelf to the west of Britain and Ireland and off the Atlantic coasts of France, Spain, and Portugal (<0.1 animals km\(^{-2}\)). It was highest in the south central North Sea and coastal waters of northwest Denmark (~0.6 animals km\(^{-2}\)). Elsewhere there was relatively little variation in porpoise density. Harbour porpoise distribution, however, has undergone a southward shift with a twofold increase in the number of porpoises in the southern North Sea strata, whereas porpoise numbers in the northern North Sea strata have halved (Figures 6.1.18 and 6.1.19). The reasons for this southward shift of harbour porpoise distribution are unknown; however, a change in distribution and availability of prey species is considered the most likely explanation, although other explanations are possible.

![density_surface_harbour_porpoise_1994](image)

**Figure 6.1.18** Density surface of harbour porpoise abundance from the SCANS I survey in 1994 (animals km\(^{-2}\)). Note the main concentrations off East Scotland and northeast England and around Denmark. Surveys were not conducted in the Irish Sea and west of Scotland.
Evidence of increased numbers of porpoises in the southern North Sea has continued to accumulate (Figure 6.1.19). From sightings during two aerial observation flights (modified pollution control flights) performed by MUMM (Management Unit of Mathematical Models for the North Sea, in Brussels) it was (roughly) estimated that the average density of porpoises in Belgian waters in March and April 2004 was between 0.2 to 0.6 per square km, or 650 to 2100 animals (Haelters and Jacques, 2006). The numbers of porpoises in Belgian waters in summer and autumn are much lower. Long-term passive acoustic monitoring has been conducted in the German Baltic Sea from August 2002 to December 2005 with porpoise detectors (T-PODs). Results show seasonal as well as geographical variations in harbour porpoise presence (and therefore abundance), with decreasing detections from west to east and with more porpoises in summer than in winter (Verfuß et al., 2007). 2006 data show similar results (Verfuß, pers. comm.).
Figure 6.1.19b  Increase of porpoises stranding on the French, Belgian, and Dutch coasts between 2000 and 2006 (no data for the French coast for 2006 available yet) (compiled from RBINS/MUMM, unpublished; ASCOBANS, 2007).

Knowledge gaps

Many of the issues which arise in the North Sea, and for which additional research is necessary for improved scientific advice, are also issues in the other ecological areas. However, because of the greater availability of data and information for the North Sea, and the focused scientific effort historically and currently through, for example REGNS (ICES, 2006), it may be appropriate to highlight the research needs for this area. Progress in this area should be viewed with regard to implications for other areas, however, and opportunities for collaborative and integrative work should be sought.

Needs for research includes:

- Community ecology: what are the ecological effects of a diminishing size spectrum and a dominance of prey species like herring, and can these changes be readily reversed through management?
- Temperature preferences, i.e. what are the effects of climate change on reproduction, egg mortality, growth, and the implications for changes in stock population dynamics and distributions?
- What are the consequences of the loss of meta-population structure and erosion of spawning aggregations in depleted populations?
- There should be better estimations of population fecundity, i.e. a better understanding of reproduction biology including better estimates of maturity ogives, variation in maturation rates, the linkage between maturation and growth, temperature – all of this for a more realistic view of stock productivity.

Using this information, it is important to investigate and test management strategies which would be sustainable in the face of these dynamic ecological conditions – how to preserve the productivity of the seas and have some revenues from fishing at the same time.

6.1.2 Major environmental influences on ecosystem dynamics

No environmental signals were identified to be specifically considered in assessment or management in this area in 2007. It should be noted that SST across much of the North Sea was close to the mean from January to August 2005, but showed strong positive anomalies thereafter. In contrast the inflowing Atlantic water was well above average temperature and salinity throughout the year.

The observed low abundance of species that play an important role in the North Sea foodweb (Calanus, sandeels, and Norway pout) has persisted into 2005 and is expected to have considerable impact on growth, maturation, and possibly recruitment of a range of fish species, and on the breeding success of seabirds.

Many North Sea fish stocks presently remain low or depleted (e.g. cod, whiting and sole). Recruitment of some commercially important gadoids is at a low level and this has led to speculation that the ecosystem may be changing in
an irreversible direction. However, there are preliminary indications of improved recruitment in some parts of the North Sea for haddock and possibly a very localized recruitment of cod. Thus far these should not be taken as indicating a major recovery in gadoid recruitment in the North Sea. An increase in a number of southern species has been noted, e.g. anchovy (*Engraulis encrasica) and red mullet (*Mullus surmuletus*). In the latter case a new fishery is developing.

The eastern channel is included in the North Sea regional ecosystem area. Studies of the fish, cephalopod, and macroinvertebrate assemblages in this area have identified four distinct community types that are determined by environmental factors such as depth, salinity, water temperature, seabed shear stress, and sediment type. Although these communities display significant interannual variation in overall community structure and composition, the different communities and their spatial distribution are persistent over time, reflecting the relative stability of environmental conditions in the area. The different communities differ in their species diversity. Overall, however, species diversity over the entire region appears to have increased over the last two decades, and is highest in areas with soft sediment and a wide variation in temperature and salinity (Vaz et al., 2007).

6.2 Human impacts on the ecosystem

6.2.1 Fishery effects on benthos and fish communities

Large-scale discarding is known to occur in the mixed demersal trawl fisheries in the North Sea. In the roundfish fishery (cod, haddock, whiting) discards will mainly consist of small-sized specimens of the target species. In the flatfish (plaice, sole) and the *Nephrops* fisheries there is also discarding of a variety of macrobenthos species.

Bottom trawling modifies the biomass, production, size structure, and diversity of benthic communities, with the intensity and patchiness of bottom trawling disturbance determining the aggregate impacts. Vast oyster beds that no longer exist were described, in the open North Sea (Olsen, 1883) and in the Wadden Sea (Hagmeier and Kändler, 1927; Linke, 1937). Early, pre-industrial trawl fisheries in the North Sea targeted oysters already in the 18th century and overexploitation is important in explaining the early extermination of these populations (Reise, 1982; Neudecker, 1990).

Recent estimates suggest that beam trawling in the southern and central North Sea beam trawl fleets removes 39% of the standing-crop biomass on an annual basis and reduces benthic production by 15% relative to the unfished state (Greenstreet et al., in press). In the northern North Sea the impact of otter trawling is less severe, with an estimate of the benthic invertebrate annual mortality due to fishing representing approximately 25% of the standing-crop biomass (Greenstreet et al., in press). Historically trawling effort has not been homogeneous, with effort greatly concentrated in preferred historic fishing grounds (Greenstreet et al., 1999, 2006; Jennings et al., 1999; Greenstreet et al., in press; Piet et al., 2000; Piet et al., in press; Rijnsdorp et al., 1998). Cumulative trawling impacts would increase if trawling effort were spread more homogeneously or relocated, particularly to more vulnerable habitats, because the first impacts of trawling on a previously untrawled community are greater than subsequent effects (Duplisea et al., 2002). For example, the cod box closure of 2001 led to the beam trawl vessels fishing in previously unimpacted areas (Rijnsdorp et al., 2001), and led to a greater reduction in the total productivity of benthic communities (Dimmore et al., 2003).

Closed areas and/or seasons generally result in effort redistribution, which may lead to increased fishery impacts on benthic communities and vulnerable habitats or species (Greenstreet et al., in press). This should be taken into account when evaluating proposed closed areas or seasons.

The principal effects of fishing on the size and species composition of the North Sea fish community has been that as fishing mortality increased, the mean size of individuals in the community decreased, and species with larger body sizes formed a smaller proportion of community biomass (Gislason and Sinclair, 2000; Jennings et al., 1999; Greenstreet and Rogers, 2006). This is reflected in the steeper slopes of size spectra (Rice and Gislason, 1996), reductions in the abundance of large species, such as many elasmobranchs, with low intrinsic rates of increase (Walker and Hislop, 1998) and increases in the abundance of many smaller species (Greenstreet and Hall, 1996; Heessen and Daan, 1996; Greenstreet et al., 1999). The changes in size composition of the fish community could change the predation mortality among species and sizes of fish. Changes in size composition of species and communities due to overfishing can also affect population fecundity both directly (reduction of larger, more fecund spawners), and indirectly (earlier maturation at smaller sizes).

Recent studies (Rochet et al., 2005), based on IBTS data from the southern North Sea 1990–2000, developed a diagnostic based on indicators for 13 fish populations and the fish community. The study demonstrated deteriorating trends in the populations and a stable community status (i.e. not improving compared to the start of the time-series in 1990). The overall conclusion showed a deteriorating situation.

The long-term effects of an eroded population structure must be considered. The differences between the various subpopulations may be behavioural or genetic, but go unobserved by both fishers and regulators who believe there is a gradual decline in one big stock while in fact they are witnessing the successive disappearance of a series of sub-
populations. Fishing also has differential effects on species with contrasting life histories (Jennings et al., 1999), with many large and vulnerable species subject to unsustainable mortality rates when taken as bycatch in mixed fisheries. Management should take account of the status of these species, and ensure that fishing mortality on bycatch species does not exceed estimates of sustainable mortality for vulnerable species (e.g. Pope et al., 2000).

The way in which each type of fishing activity affects eight separate ecosystem components (habitats, nutrients, plankton, benthos, the fish community, commercial fish and shellfish, marine mammals, and seabirds) within the North Sea was described in detail by WGECO (ICES, 2006). Two EC-funded projects have compiled international fishing effort databases for the major gear categories spanning the periods 1990 to 1995 and 1997 to 2004 (Jennings et al., 1999; Greenstreet et al., in press). These two studies indicate that the distribution of fishing activity has changed very little over the combined 14-year period. The pattern of impact on benthic and fish communities is likely to have varied very little across the North Sea. Any variation in impact will have been driven by overall changes in the levels of different types of fishing activity taking place across the whole North Sea. The MAFCONS dataset suggests that fishing activity overall has declined markedly, by approximately 28%, since 1999. However, this overall decline masked very different changes taking place when each fishing activity category was considered independently. Beam trawl effort, otter trawl effort directed at fish, and seine gear effort all declined by 31%, 44%, and 62%, respectively; however, otter trawl effort directed at Nephrops increased by 65% (Greenstreet et al., in press).

Links between North Sea plankton, fish stocks, fisheries, and seabirds

This description builds upon the existing knowledge available on the structure and function of the North Sea marine ecosystem (Jones, 1982; Heath, 2005). For example, it is known that energy, in the form of carbon and nutrients, flows between the trophic levels as a result of predator–prey interactions and that these interactions to a large extent are size-based such that numerous small animals tend to be eaten by rather fewer larger animals, creating complex foodwebs (Jones, 1982; Heath, 2005; Steele et al., 2007). The recycling of carbon and nutrients by micro-organisms also ensures that energy passes back down the foodweb as a series of microbial feedback loops and that coupling between the pelagic and benthic ecosystems is maintained.

To illustrate the changes in energy cycling in the North Sea foodweb, two 11-year periods were distinguished: 1983–1993 (Figure 6.1.20) and 1993–2003 (Figure 6.1.21).

For the earlier period (1983–1993) the results suggest a system mainly top–down regulated, as indicated by generally higher relatedness at the top than at the bottom of the foodweb. Significant top–down fishing pressure was indicated by the highest relatedness value occurring between demersal fishing pressure and demersal stocks (0.8), but also high relatedness between the pelagic fishery and pelagic stocks (0.5). For both the demersal and the pelagic ecosystems the predominant pressure acting on the North Sea ecosystem (as represented by the ecosystem components described) was from fishing and not environmental forcing. Indeed, during the 1980s a doubling of the annual sandeel landings was witnessed, from 0.5 million tonnes in 1983 to 1.1 million tonnes in 1989; landings of demersal fish such as cod were in steady decline which is usually attributed to both climate and mainly otter trawl fishing. Beam trawling effort also increased significantly over this period, putting further pressure on the system (Jennings et al., 1999). In addition, there is a significant and high degree of relatedness between seabirds and both pelagic and demersal fisheries and fish stocks. In this respect it is noteworthy that the highest value is between the demersal fishery and seabirds (0.7), possibly reflecting the increase in discards associated with the demersal fishery compared to the pelagic fishery (Furness, 2003).
Figure 6.1.20 The relatedness (or degree of connection) between ecosystem components of the North Sea for the period 1983 to 1993, highlighting a significant possible top–down pressure as a result of fishing. Numbers underlined indicate a significant correlation.

By contrast the period 1993 to 2003 (Figure 6.1.21) shows the pelagic foodweb to be bottom–up regulated, with a highest value between the abiotic and plankton components (0.6) and decreasing values further up the food chain. This system is arguably more sustainable and favourable for the maintenance of ecosystem integrity and fisheries. However, for the benthic ecosystem the relatedness between the demersal fishery and demersal fish stock components remains significantly high, albeit lower than in the pre-1993 period, suggesting top–down fishery pressure remains significant and greater than the environmental forcing. In addition, it is noteworthy that the degree of relatedness between the seabirds and both fisheries and fish stock components has decreased over this period compared to the period 1983 to 1993, which is perhaps to be expected given the overall decline in fish discards (as inferred from the overall decline in demersal fish landings) over the assessment period. Interestingly, a similar decline has been described in the seabird populations in the North Sea, particularly for the northern fulmar and black-legged kittiwake (Parsons et al., in press).
Figure 6.1.21 The relatedness (or degree of connection) between ecosystem components of the North Sea for the period 1993 to 2003, highlighting a significant bottom-up pressure for the pelagic ecosystem and top-down pressure for the benthic ecosystem. Numbers underlined indicate a significant correlation.

References


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