chapter 5

Biology

5.1 Introduction

The 1993 QSR described the complexity of biological systems and the inter-relationships between communities in the North Sea and drew attention to the effects of human activities on the North Sea marine ecosystems. This chapter combines a brief overview of the flora and fauna in the Greater North Sea with an updated description of demonstrated and potential effects of human impact on the biological system.

5.2 General description of the ecosystem of the Greater North Sea

5.2.1 Biological inventory of the area

Plankton

Physical factors, particularly stratification due to water mass density differences, play a significant role in structuring the pelagic ecosystems of the Greater North Sea. This is particularly manifest in changes in the structure of plankton food webs, greater matter and energy cycling within the water column, and changed flux of material to the benthos (Hagström *et al*., 1996) *(Figure 5.1)*.

Except for relatively short periods when there is high availability of light and nutrients, the phytoplankton of the open (stratified) North Sea are resource limited, there is light limitation in winter, and nutrient limitation in the water above the thermocline in summer. In contrast to coastal areas, in both winter and summer the open sea planktonic system is dominated by pico- and nanoplankton. Substantial increase in biomass of larger phytoplankton species occurs only during transient phases between lengthy periods of limitation (Riegman *et al*., 1998).

The size-classes of algae involved in blooms are controlled, in normal conditions, by the grazer community. The algae in the pico and nano size ranges are effectively controlled by their microzoo-planktonic grazers. Mesozooplankton show a much slower population response, and this lack of control allows for rapid biomass increases of the larger algae. Diatoms and flagellates fluctuate along different annual cycles with particularly large inter-annual fluctuations in summer dinoflagellate stocks. Nanoplankton population densities appear to have increased sharply at the end of the 1970s.

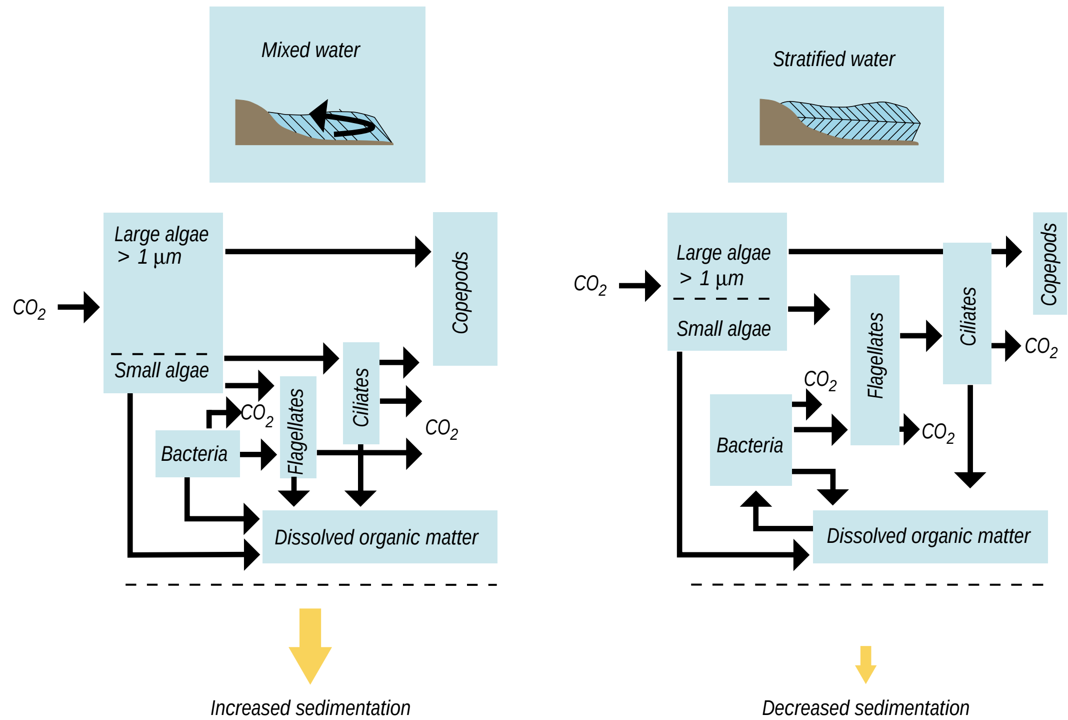
Long-term biomass estimates of micro- and nanoplankton in the German Bight near Helgoland indicate sources of variation including both seasonal succession and changes due to shifts in the hydrographic structure of the nearby stratified water masses. Any changes due to increasing nutrient concentrations are masked by the overriding effect of the local hydrographic regime.

Though bacteria and viruses are important functional components of the Greater North Sea ecosystem, data on the specific roles and ecology of these two groups are currently too sparse to allow an assessment. Given the overall importance of microbiota in the functioning of the Greater North Sea ecosystem, additional research is strongly recommended.

Benthos

In shallow shelf areas such as the North Sea, benthic and

Figure 5.1 **Conceptual model of the North Sea ecosystem under stratified and non-stratified water conditions. Source: modified from Hagström *et al*. (1996).**



pelagic processes are often strongly coupled and work in concert to make the region extremely productive. Sediments in particular show many spatially tight, and geochemically important, linked relationships, many of which are subject to modification by human impact.

Time series from the Norderney offshore area and Kattegat indicate a correlation between population dynamics and certain climate factors such as the North Atlantic Oscillation (Tunberg and Nelson, 1998). However, changes in benthic populations are also correlated with changes in eutrophication status.

Twenty-six benthic stations in the German Bight were sampled from April through October 1995 and the results were compared to those of former investigations. Numbers of species, population density and biomass were the highest since the early quantitative investigations in 1923/4 (*Table 5.1* and *Figure 5.2*). Biomass has tripled in the past ten years in muddy areas of the German Bight, perhaps in part due to eutrophication. A comparison of investigations made in 1975 and 1995 shows that despite major changes in the faunal composition, the geographical distribution limits of the macrozoobenthos communities in the German Bight have been relatively stable in recent times (Richter, 1996).

The inter-annual variability in biomass, abundance and species number of macrofauna collected seasonally from 1978 to 1995 off Norderney has been related to inter-annual climate variability. It appears that mild meteorological conditions, probably acting in conjunction with eutrophication, have resulted in a general increase in total biomass since 1989.

The reef building polychaete *Sabellaria* sp., a common sublittoral species in the Wadden Sea in the first part of the century, is now re-occurring at only two locations in the German part of the Wadden Sea. Extensive reefs no longer exist.

The sediments of intertidal flats are colonised by hundreds of species of microscopic benthic algae. Most of them are diatoms, whose populations are also accompanied by cyanobacteria (blue-green algae) and interstitial flagellates.

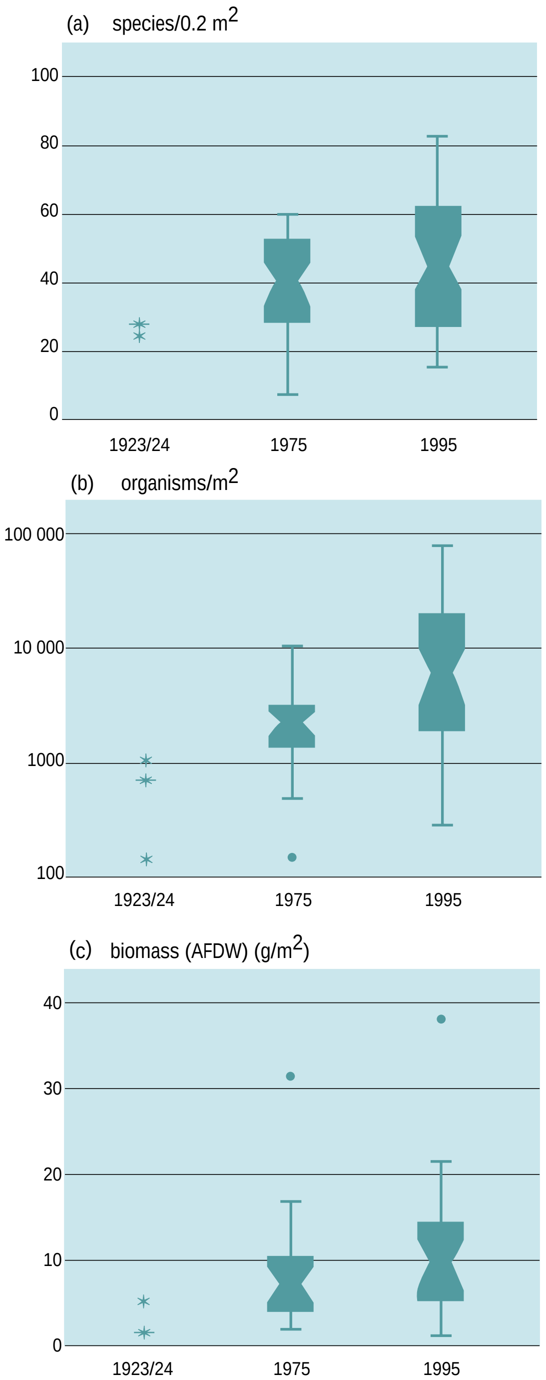
Microphytobenthos is a primary source of nutrition in shallow waters for larger grazers and fish (e.g. mullet, *Crenimugil labrosus*). Microphytobenthos suspended by wave action have been calculated to constitute up to 90% of the primary production in the water column and are probably important as a food source for filter-feeding bivalves. They form an important part of a food web through mudsnails and their predators, shore crabs (*Carcinus maenas*), shrimps (e.g. the brown shrimp (*Crangon crangon*)) and shelduck (*Tadorna tadorna*) (De Jonge, 1994).

Before 1930 subtidal populations of the eelgrass *Zostera marina* covered vast areas in the Wadden Sea. After a disease epidemic caused by the protozoan *Labyrinthula macrocystis* in the early 1930s the subtidal seagrass beds completely disappeared and were unable to re-establish themselves. In the Dutch Wadden Sea only a few scattered seagrass stands have survived. The eelgrass stand in the Ems estuary has increased from 13 to more than 100 ha in the last 10 years. This increase is in part due to protection from damage by the shellfishery.

Table 5.1 General trends in benthic fauna of the German Bight since 1923/4. A key causal factor behind these trends is likely to be the demersal fishery. Source: Lindeboom and de Groot (1998).

Increasing Trend	Decreasing Trend
Abundance and biomass of *Phoronis* spp.	
Abundance and biomass of suspension feeding Polychaetes:	
Owenia fusifomis	
Lanice conchilega	
Magellona spp.	
Spionidae	
Abundance of some predatory polychaetes:	
Nephtys spp.	
Nereis spp.	
Abundance of brittlestars:	
Amphiuridae	
Ophiuridae	
Abundance of cumaceans:	
Pseudocuma longicornis	
Eudorella emarginata	Overall biomass of echinoderms
Abundance of smaller bivalves:	Abundance of larger long-lived bivalves:
Abra spp.	*Arctica islandica*
Tellimya ferruginosa	*Chamelea gallina*
Tellina fabula	Overall biomass of molluscs

Figure 5.2 **Notched box and whisker plots of: (a) numbers of species, (b) individuals and (c) biomass of North Sea benthic macrofauna 1923–1995. Values from 1923/4 are average values for the sampled communities and are marked by a line and an asterisk. Central notch or 'waist' is equal to the sample median; the points at which the notch first expands to full box width designates the upper and lower 95% confidence values of this median. Source: modified from Lindeboom and de Groot (1998).**



Although a recent local reestablishment of the eelgrass *Zostera noltii* has occurred, the overall population decline has continued. Possible factors influencing this decline are eutrophication, the presence of phytotoxic pollutants like herbicides, increased water turbidity and macroalgal blooms (De Jong *et al*., 1999).

In the littoral and upper sublittoral zones perennial fucoids (e.g. knotted wrack, bladder wrack (*Fucus vesiculosus*) and serrated wrack (*Fucus serratus*)) compete for space with annual green algae. In deeper water species of kelp (e.g. *Laminaria hyperborea*) tend to dominate. These species form dense forests and are exploited in several countries. Numerous (approximately 700) macroalgal species are found in the Channel area (Cabioch *et al*., 1992). The most developed macroalgal communities in the region are found on rocky shores and on hard bottoms in the sublittoral zone down to approximately 15 m in southern and 30 m in northern parts of the North Sea.

Fish

Approximately 230 species of fish are known to inhabit the North Sea of which 13 are the main targets of major commercial fisheries (cod, haddock, whiting, saithe, plaice, sole, mackerel, herring, Norway pout, sprat, sandeel, Norway lobster, and deep-water prawn). Norway pout, sprat and sandeel are predominantly the targets of industrial fisheries where the catch is converted into fish meal and oil while the other species are the targets of fisheries where the catch is used for direct human consumption.

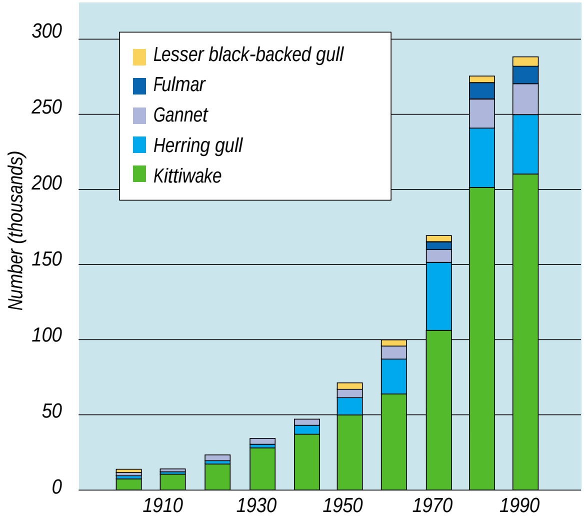
Fish species diversity is low in the shallow southern North Sea and eastern Channel and increases westwards. Species diversity is also generally higher inshore (Greenstreet and Hall, 1996) as the variety of sediment types and spatial niches increases.

Most of the variability of the fish stocks is due to variation in egg and larval survival which is thought to be regulated by density-independent factors, such as sea temperature and currents affecting larval drift to nursery grounds, as well as density-dependent predation on the eggs and larvae. Annual variability in recruitment of juveniles to the parent stock can differ by a factor of 5 for plaice, 50 for sole and more than 100 for haddock. Most species show annual or inter-annual movements related to feeding and spawning.

Birds

Seabirds are generally characterised by high annual survival rates, maturity at high age and low reproductive rates. Many shorebirds, such as waders and ducks, feed in intertidal areas along the coast. The Wadden Sea is of particular importance for both breeding and migratory bird populations. Six to twelve million birds of more than 50 different species occur there annually. Coastal waters are also of importance as wintering and migratory staging areas for waterfowl. A number of species of scavengers

Figure 5.3 **Number of breeding pairs of scavenging seabirds in Shetland, Orkney, Caithness to Banff and Buchan. Source: redrawn from 5NSC (1997).**



have experienced large population size increases throughout this century *(Figure 5.3)*.

Some 10 million seabirds are present in the North Sea at most times of the year. In summer more than four million seabirds of 28 species breed along the coasts of the North Sea. During autumn many species leave the area, but are replaced by visitors from northern and western waters. The bird migrations and seasonal shifts in distribution are pronounced.

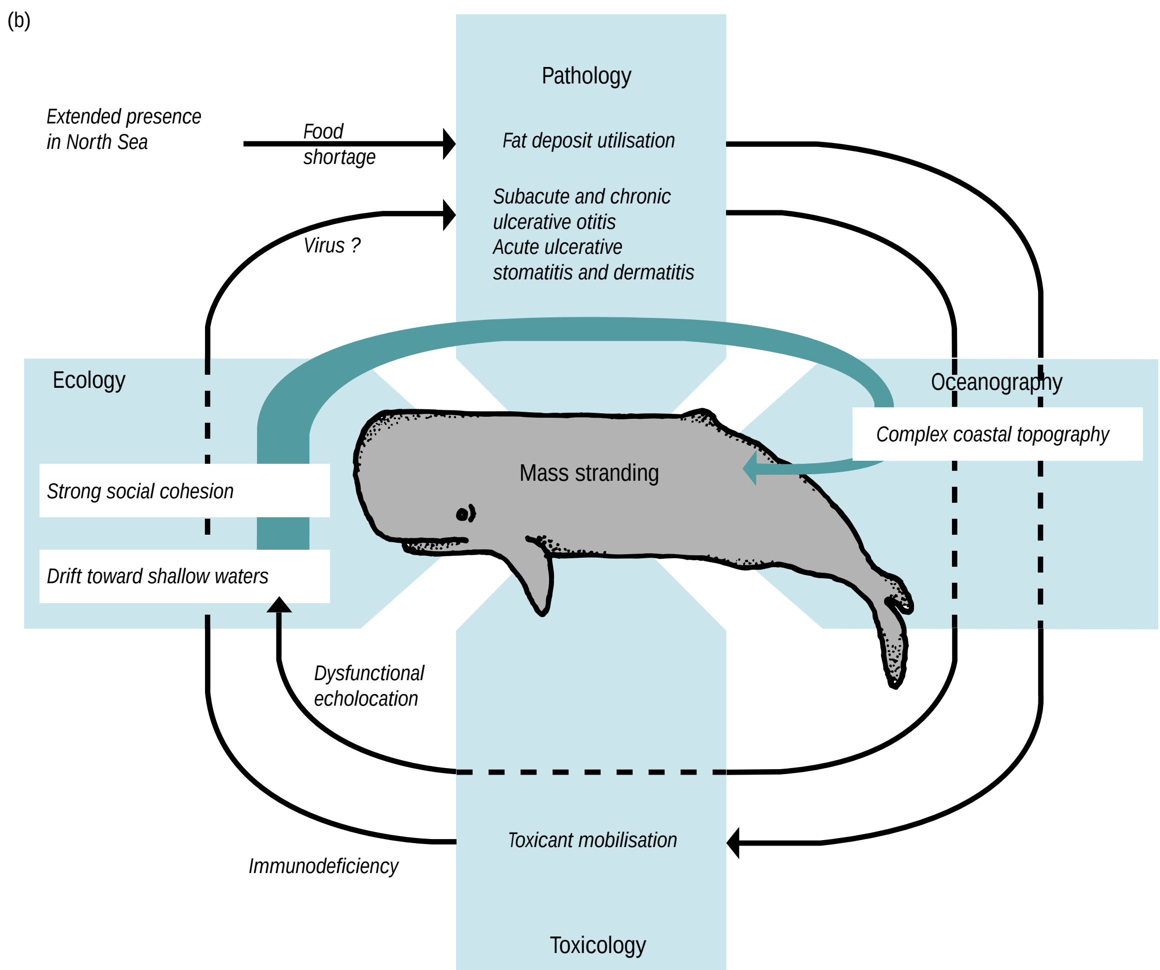
An offshore and an inshore group can be identified among the seabirds. The offshore group includes fulmars, petrels, gannets, some gulls, and most auks. These birds breed on the coasts of the North Sea and the Channel, but frequently feed far offshore with a significant portion of their diet likely to be provided by the fishery (Lindeboom and de Groot, 1998; see section 5.3.4). Inshore birds include the seaducks, divers, cormorants, terns, some gull species and the black guillemot (*Cepphus grylle*). Many seabirds are present in numbers that represent substantial proportions of their world population, although none is endemic. The North Sea coasts support over 50% of the total world wide number of common terns (*Sterna hirundo*) and great skuas (*Catharacta skua*), and a further 12 species, such as the black scoter (*Melanitta nigra*) around the Flemish Banks, are present in numbers exceeding 10% of their total estimated populations.

Many species reached their greatest population sizes after the 1990s. It has been suggested that causes of the increases are improved protection since the 1920s, increased populations of small prey fish, and increased supply of discards and offal from fisheries (which may have induced increases in populations of some species of birds to levels greater than would otherwise have been possible). In contrast, human disturbance may have reduced the numbers and breeding success of several species. Culling of herring gulls as a protective measure for other bird species is no longer practised (Hüppop, 1997).

Table 5.2 Estimated numbers of seals, harbour porpoises, dolphins and minke whales in the North Sea.

Harbour seal (*Phoca vitulina*)			
	Norway	west coast and North Sea coast, Oslofjord	3 400
	United Kingdom	Orkney, Shetland	14 100
		East Scotland	1 700
		East England	
	Wadden Sea		7 040
	Danish Limfjord		700
	Kattegat/Skagerrak		6 300
Grey seal (*Halichoerus grypus*)			
	Norway	Entire coastline	2 100
	United Kingdom	North Sea	58 300
	Wadden Sea		250
	Kattegat		< 25
Harbour porpoise (*Phocoena phocoena*)		North Sea	268 300
Minke whale *(Balaenoptera acutorostrata)*		North Sea	7 200 – 20 000
Whitebeaked/whitesided dolphin *(Lagenorhynchus albirostris/L. acutus)*		North Sea	10 900

Figure 5.4 **(a) Sperm whale stranding, the Netherlands. (Photo: Rijkswaterstaat).**
(b) Hypothesized causes of North Sea sperm whale strandings.



Marine mammals

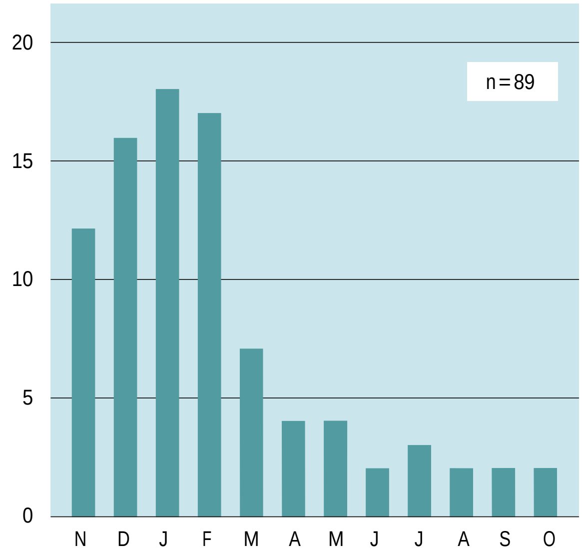
Counts of common seal numbers (1994–6) estimate the current North Sea population at 36 000 seals. The Wadden Sea population was reduced from 10 000 to 4 000 after the 1988 epidemic. Since 1989 numbers have increased to more than 14 000 (counted in 1998; Reijnders and Reineking, 1999). On balance, therefore, common seal populations in the North Sea have either not changed or have increased since 1988.

The first detailed survey of small cetacean populations in the North Sea was carried out in 1994. The most commonly observed cetacean is the harbour porpoise (estimated at 300 000 individuals) (Hammond *et al*., 1995). Estimated numbers of the most common mammal species in the North Sea are presented in *Table 5.2*.

Other species of toothed whale that are sighted regularly in the North Sea include the long-finned pilot whale (*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 all other species of cetacean are relatively rare (Hammond *et al*., 1996).

There appears to be an overall recent increase in cetacean strandings in the North Sea area which, by hypothesis, has been related to an overall increase in population sizes for some species, particularly sperm whales (*Physeter macrocephalus*), due to their protected status (*Figures 5.4a* and *b*). Groups of male sperm whales occasionally visit the North Sea, particularly in the period between November and March during their southward migration, and strandings have been most frequent during these months *(Figure 5.5)*. Strandings, occasionally in groups, typically occur in the southern regions where the coastal topography is characterised by extensive sandbanks, mudflats and estuaries. Fossil data indicate that though relatively rare, this phenomenon has been occurring for thousands of years (De Smet, 1997).

Figure 5.5 **Compilation of historical data (1560–1995) for North Sea sperm whale strandings by month. Source: modified from Smeenk (1997).**



5.2.2 Particular habitats and key species

There are presently several key activities implementing the OSPAR Strategy for the Protection and Conservation of Ecosystems and Biological Diversity and utilising the ecosystem approach as agreed by IMM. Activities include elaboration of a habitat classification scheme and development of lists where endangered species and habitats are identified. In addition an inventory of marine protected areas is being made.

5.3 Impact of Human Activities

Many human activities have impacts on the biology of the Greater North Sea. Most notable are the effects of fisheries and eutrophication, but changes in the environment caused by exploitation of mineral resources (including oil and natural gas), shipping, chemical contamination, construction, tourism and dredging are also important.

5.3.1 Impact of non-indigenous species

A species is considered non-indigenous to the North Sea if its natural (i.e. historical) range of occurrence is geographically remote from the North Sea. Species that arrive in the North Sea region as a result of simple range expansion are not considered non-indigenous. Regardless of the nature of colonisation, some invading species are undesirable for economic, aesthetic or ecological reasons.

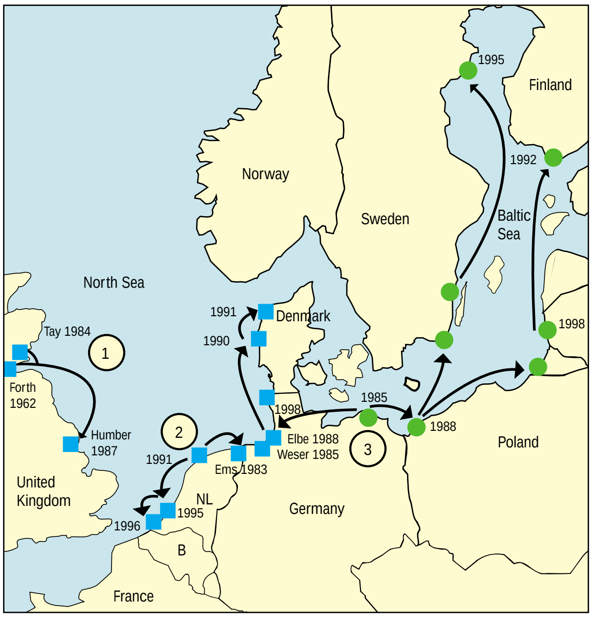
Non-indigenous species may arrive in the North Sea as a result of both natural (e.g. currents) and human-mediated processes (e.g. ships' ballast water, transport of fish and shellfish, organisms attached to ships' hulls, and mariculture). In many cases it is not possible to determine which vector was responsible.

Japanese seaweed (*Sargassum muticum*), a brown alga , was probably introduced via shipments of the Pacific oyster (*Crassostrea gigas*) for mariculture in France in the early 1970s (Critchley, 1983). This brown alga has spread widely along the coastline of the other North Sea countries. The Japanese seaweed can be quite long (10 m) and sometimes clogs bays and harbours. It also competes with other macroalgae for space.

The Pacific oyster has also spread over the Wadden Sea area. In the late 1990s several local populations have been thriving in the lower intertidal area of the Dutch and German Wadden Sea.

Likely introductions via ballast water are the North American razor clam (*Ensis directus*, Syn: *E. americanus*) and polychaetes of the *Marenzelleria* species group *(Figure 5.6)*. In the 1980s the North American razor clam spread along the eastern shores of the North Sea, and is now present from the Kattegat to the river Seine and the south-east coast of England (ICES, 1998b). There are as yet no indications that any indigenous species have been outcompeted by this newcomer.

Figure 5.6 **Three sites primary of introduction and spread of the North American spionid polychaete *Marenzelleria* sp. into the North Sea beginning in 1982: (1) Forth Estuary, Scotland (1982), (2) Ems Estuary, The Netherlands (1983), (3) Darss-Zingst Bodden area in the German Baltic Sea (1985). Source: K. Essink.**



5.3.2 Harmful algal blooms

Approximately twenty North Sea phytoplankton species produce toxins, some of which affect fish directly (ichthyotoxins). Their effect on man is usually indirect. Mussels concentrate toxins in the hepatopancreas and human consumption of such mussels occasionally causes fatal poisoning. Poisoning is classified according to the symptoms caused by the chemically very different toxins and includes paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP) and amnesic shellfish poisoning (ASP). There is no evidence of increased incidence of harmful algal blooms in the North Sea over the last 5 – 10 years.

Various ichthyotoxins of largely unknown chemical composition are produced by phytoplankton species from different groups, including the dinoflagellates (*Gyrodinium aureolum*) and Prymnesiophycea (*Chrysochromulina polylepis, Prymnesium parvum*). Hepatotoxins affecting humans are produced by cyanobacteria.

The occurrence of harmful algal blooms is favoured by the ability of several algae to form resting stages which sink to the sea floor and remain capable of reproduction for several years. Such resting stages reproduce under suitable environmental conditions and better knowledge on this process is badly needed. Resting stages spread easily in ballast water of vessels or in aquaculture products (mussel and oyster larvae).

In May 1998, the raphidophyte *Chattonella verriculosa* caused fish mortality in the North Sea and Skagerrak. Related potentially toxic species *Chattonella antiqua, C. marina, Fibrocapsa japonica* and *Heterosigma akashiwo* have been found to occur in Dutch coastal waters since 1991 (Vrieling *et al.*, 1995). In the summer of 1997 *Fibrocapsa japonica* was found in almost all samples from the Dutch 'Algal Bloom Programme'. In Germany the species has been observed near Sylt, the German Bight and in the Wadden Sea on the west coast of Schleswig-Holstein (Rademaker *et al.*, 1998, Vrieling *et al.*, 1995). The algal toxin fibrocapsine produced by the alga *Fibrocapsa japonica* has been demonstrated in dead common 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.

Noxious blooms of *Phaeocystis* and *Coscinodiscus* recur on the south-eastern and eastern coasts of the North Sea. *Coscinodiscus* is especially unpleasant for fisherman and harmful to fish because it causes increased mucus production by the fish which can occasionally lead to blockage of gill function. The foam production following *Phaeocystis* blooms could also be considered as a nuisance.

The dinoflagellate *Gyrodinium aureolum* was first observed in northern European waters in 1966 and has 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. A number of the blooms appear to have originated in the open waters of the Skagerrak and Kattegat and spread with the coastal current *(Figure 5.7)*.

5.3.3 Impact of microbiological pollution

The two main health-related areas of microbiological pollution are the microbiological quality of bathing water, and the quality of seafood (primarily shellfish).

Bathing water quality

Recent EC reports (European Commission, 1994–8)

Figure 5.7 **Geographic distribution of blooms of *Gyrodinium aureolum* in the eastern North Sea and Skagerrak. Source: modified from Skjoldal *et al*. (1997).**

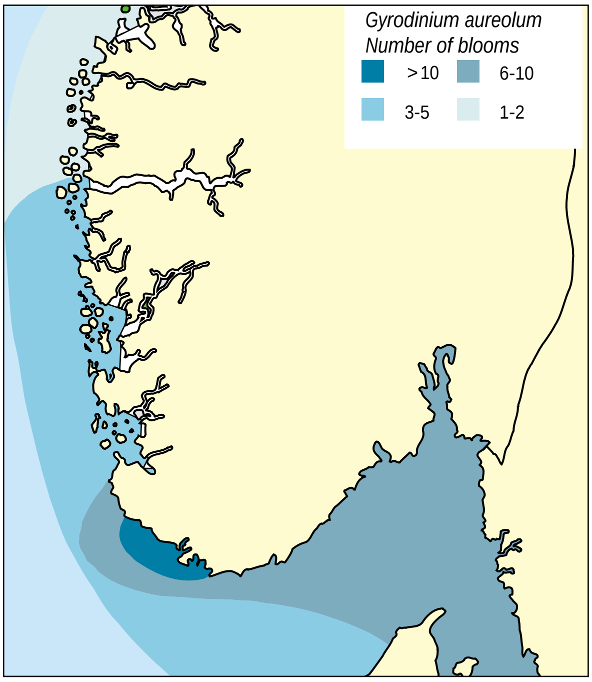
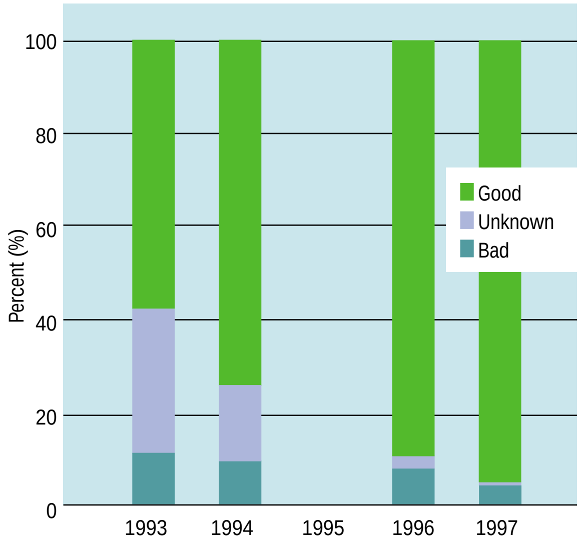


Figure 5.8 **An overview of bathing water quality for the years 1993 to 1997 based on an assessment of the data published by the European Commission (Forbes and Brans, unpubl.).**



show that bathing water quality has improved in the last two years, which was attributed to improvements in waste water treatment. Where bathing waters failed to meet the requirements of the EEC Bathing Water Directive (76/160/EEC) despite improvements in waste water treatment and compliance with regard to hygiene requirements for the relevant beaches, this may be attributable to diffuse sources of pollution such as run-off of manure.

Although since 1996 the evaluation included biological and physico-chemical parameters, only biological data were used to construct *Figure 5.8*. An increase in the proportion of 'good' locations could be observed, partly because of better information which decreased the number of 'unknown' locations. A lack of harmonised methods makes it very difficult to compare countries.

Seafood quality

PSP was first described in the early twentieth century and observed in Denmark and Sweden in the 1980s, but thanks to effective monitoring there have been only minor economic losses to the industry and a minimal threat to human health.

In the Skagerrak and Kattegat the content of bacteria (coliforms) in seafood is a minor problem but accumulation of algal toxins has created major problems for mussel cultivation, and to some extent to the cultivation of salmonids.

5.3.4 Impact of fisheries on ecosystems

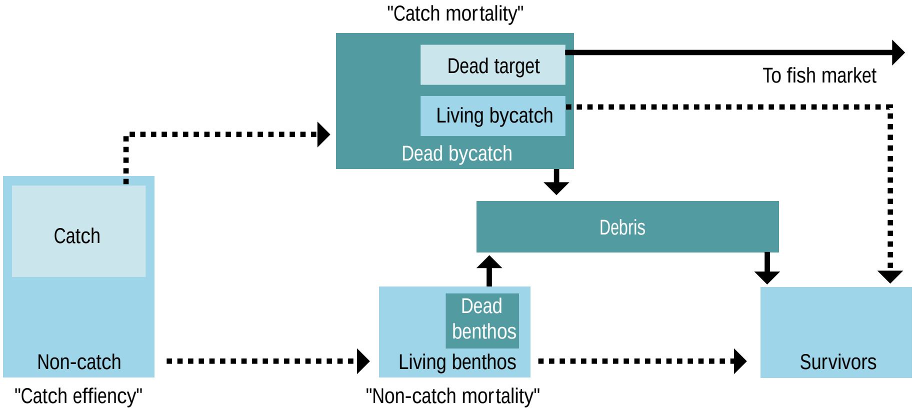
There are three principle effects of fishing activity on North Sea ecosystems. The first is due to direct fishing pressure. Capture of fish and shellfish leads to mortality of both target and non-target species. A second important effect is due to the practice of discarding which can significantly impact the ecology of scavengers and predators. Finally, there are direct and indirect effects on benthic communities through direct physical disturbance of sediment by trawling as well as increased organic input derived from discards *(Figure 5.9)*.

The most obvious direct effect of fishing is the physical removal of fish and shellfish from the habitat. At present between 30 and 40% of the biomass of commercially exploited fish species in the North Sea is caught each year.

Most studies investigating the direct effects of fishing on benthic communities in the North Sea have been conducted at depths of 100 m or less (Lindeboom and de Groot, 1998; Rogers *et al*., 1998b) where much of the fishing activity with towed gears takes place. Environments at these depths experience continual natural disturbance due to storms and strong tidal currents. The ecological impacts of towed fishing gears in the North Sea depend on the relative magnitude of fishing and natural disturbance, and the effects of fishing are harder to detect on mobile sediments in shallow water.

Demersal bottom feeders (e.g. cod, plaice) are attracted to trawling sites and often feed on benthic invertebrates which appear to be made more susceptible to fish predation from the disturbance. Though not well studied, these indirect effects on fish diets, benthic

Figure 5.9 **Direct effect of beam trawling on demersal fish and benthic invertebrates as related to: (1) the catch efficiency (the number of fish and invertebrates caught in the net divided by the total number in the trawl track before fishing), (2) the catch mortality (the number of dead fish and invertebrates in the catch divided by total number caught), and (3) the non-catch mortality (the number of dead fish and invertebrates in the trawl track divided by the total number of animals in the trawl track after fishing). Solid arrows represent fluxes of dead animals, and dotted arrows fluxes of (initially) living animals. Source: modified from Lindeboom and de Groot (1998).**



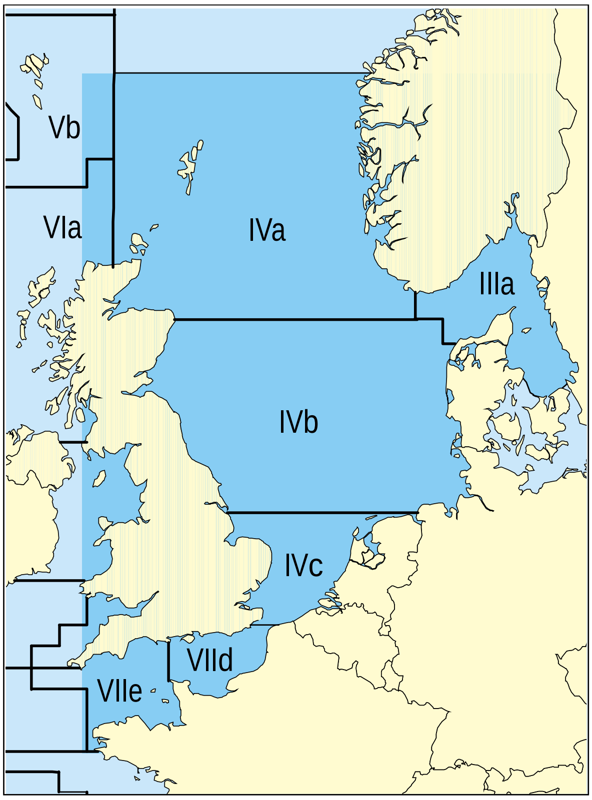
predation rates and the resultant shifts in trophic dynamics and community structure are likely important determinants of present day ecosystem functioning.

Impact on stocks of target and non-target fish species (including bycatch and discards)

Target fish species. The long-term effects of high fishing mortality have resulted in a decrease in abundance in older age groups of target species. Significant effects of fishing on the size composition of the exploited North Sea fish assemblage (Rice and Gislason 1996; ICES 1998a) are thought to result from both this direct exploitation and the induced modifications of predator-prey relationships. At various times during the last 10 years the North Sea stocks of cod, haddock, whiting, saithe, plaice and herring have dropped to or below any previously recorded level (5NSC, 1997). The spawning stock of mackerel has not yet recovered since its collapse in the mid-1960s. In the case of cod, haddock, and herring, recovery has been in evidence in recent years. However, all the major stocks of roundfish and flatfish and also the herring stock are considered by ICES to be close to or outside safe biological limits (*Table 5.3* and *Figure 5.10*).

The ICES Advisory Committee on Fishery Management has long advocated reduction in fishing effort on these stocks. In 1998, this committee put forward advice based on the application of the precautionary approach for the management of these (and many other) stocks. This advice has been implemented fully for herring, and partially for mackerel and plaice. Further consideration of implementation with respect to mackerel, plaice, cod, whiting, and saithe took place during 1999.

Figure 5.10 **ICES Sub-areas and Divisions in Region II.**



The stocks of Norway pout and sandeel are considered by ICES to be within safe biological limits. No analytical assessment is available of the status of the stock of sprat.

Table 5.3 Assessment of North Sea fish stocks in relation to ICES areas shown in Figure 5.10. Source ICES (1999a,b).

Stock	ICES Area	Assessment
Cod *(Gadus morhua)*	IV, VIId, IIIa (Skagerrak)	Below SBL*
Haddock *(Melonagrammus aegleinus)*	IV, IIIa	Close to SBL
Whiting *(Merlangius merlangus)*	IV, VIId	Below SBL
Saithe *(Pollachius virens)*	IV, IIIa	Below SBL
Plaice *(Pleuronectes platessa)*	IV	Below SBL
Sole *(Solea solea)*	IV	Below SBL
Herring (autumn spawners) *(Clupea harengus)*	IV, VIId, IIIa	Below SBL
Downs Herring	IVc, VIId	Below SBL
Sprat *(Sprattus sprattus)*	IV	Unknown
Mackerel (North Sea) *(Scomber scombrus)*	IV	Collapsed
Horse Mackerel (North Sea) *(Trachurus trachurus)*	IIIa, IVb.c,VIId	Unknown
Norway Pout *(Trisopterus esmarkii)*	IV, IIIa	Above SBL
Sandeel (*Ammodytes* sp.)	IV	Above SBL
Sandeel	IVa (Shetland)	Above SBL
Northern Prawn *(Pandalus borealis)*	IVa (Fladen Ground)	Unknown
Northern Prawn	IVb (Farn Deeps)	Unknown
Norway lobster *(Nephrops norvegicus)*	IVa (Fladen Ground)	Not fully exploited
Norway lobster	IVa (Moray Firth)	Fully exploited
Norway lobster	IVb.c. (Botney Gut, Silver Pit)	Fully exploited
Norway lobster	IVb.c. (Farn Deeps, Firth of Forth)	Fully exploited

* SBL = Safe Biological Limits.

Current levels of catch rates of the most important species in the North Sea are summarised in *Table 5.4*. About 70% of the two-year-old cod die before they reach sexual maturity, 80% of which are taken by the fishery.

Non-target fish species. A number of recent studies have investigated changes in abundance of non-target species and the results indicate few clear trends either for species or areas (ICES, 1998a). Decreases in abundance have been observed for a number of larger species of elasmobranch such as the spurdog (*Squalus acanthias*), common skate (*Raja batis*) and thornback ray (*Raja clavata*), particularly in the south-eastern North Sea (Walker and Hyslop, 1998). Increases were observed for smaller, rapidly maturing, fast growing species such as the starry skate (*Raja radiata*). It is likely that life history characteristics such as low fecundity, slow growth and late age of maturation make the elasmobranchs particularly susceptible to overfishing.

Fishing mortality is a selective force that can affect the genetic composition of a target population. Fast growing individuals tend to be selectively removed from the population and over time this may affect phenotypic traits such as size and age of maturation. In the North Sea this may happen with cod (Law and Rowell, 1993) and plaice (Rijnsdorp, 1992).

Discards, offal, bycatches and high grading. Fish and benthos that are caught and thrown back into the sea are known as 'discards'. Offal is the tissue discarded after fish are cleaned and gutted at sea. Offal corresponds to approximately 12% of the weight of landings of fish that are gutted and does not include 'slippage' which involves releasing unwanted catch from the net before it is hauled aboard. High grading is the practice of retaining only the most valuable components of a catch and also discarding marketable but less valuable fish.

Discarding is especially prevalent in those fisheries in which a mixture of species is caught because they cannot be separated prior to capture. In this connection, discarding of cod, haddock, and whiting occurs on a large scale in some areas. Some of this discarding includes high grading. Discarding by the industrial fishery is unusual. In certain fisheries (in particular for plaice and sole) more than half of the weight of the fish caught and considerable amounts of benthos may be discarded. Some of the discarded animals survive, but most are dead or dying. These discards and offal provide a source of food for a number of scavenging seabird species (Lindeboom and de Groot, 1998) which makes up to one third of their food requirement. The overall impact of discarding on North Sea ecosystems is uncertain at present.

Fisheries for Norway pout, sprat and sandeel, for industrial use, are conducted with small-meshed nets. There is little by-catch taken by the sandeel fishery. However, in those parts of the North Sea where there are fisheries for Norway pout, juvenile haddock and whiting also occur and juvenile herring occur in areas where there are sprat fisheries. There is therefore an inevitable by-catch of haddock and whiting or herring which has a minor impact on the stocks (2 – 4% of the total mortality). However the by-catch is not on a scale where it is of decisive importance to the fisheries for which these stocks are a major target (ICES, 1999b).

Effect of fisheries on marine ecosystems (including benthic communities, birds and mammals)

Towed fishing gear modifies the substrate and has direct and indirect effects on the composition and diversity of benthic communities. Physical disturbance of the substratum results from bottom contact and the resuspension of sediment. Sediments are turned over each time to a depth of at least 1 – 8 cm. Tracks may persist for a few hours in shallow waters with strong tidal currents, or for years in the deeper areas (Lindeboom and de Groot, 1998). Degree of impact depends on towing speed, gear size and weight, substrate type and local hydrodynamic

Table 5.4 Average percentages of different age groups yearly taken by fisheries in the period 1992–6. Catch rates are listed for the main fish species exploited in the North Sea. Source: ICES (1997b).

	Juveniles		Exploited groups	
Species	Age *	% caught	Age *	% caught
Cod	1	5	2-8	48
Whiting	1	6	2-6	48
Saithe	1	9	2-6	41
Sole	1	1	3-6	38
Plaice	1	1	2-8	37
Herring	1	0	2-10	33
Haddock	1	16	2-6	44
Sandeel	0	3	1-3	21
Norway Pout	0	2	1-2	15

* The range of age groups to which the estimate applies is shown. 0 refers to the 0-group fish in their first year of life, 1 to fish in their second year of life, etc.

factors. The composition and diversity of benthic communities changes because towed gear leads to differential mortality rates of component species *(Figure 5.9)*.

Benthos. Towed fishing gear in contact with the seabed kills both infauna and epifauna (*Tables 5.5* and *5.6*). Infauna are affected by equipment that penetrates the seabed, including beam trawls and the otter boards of bottom trawls. The habitat of the seabed itself is clearly affected with respect to biologically important sedimentary parameters such as penetration depth and surface roughness.

Studies of the effects of fisheries on benthos are complicated by the fact that fishing disturbance has occurred for over 100 years. There has been a shift from larger more long-lived benthic species to smaller more opportunistic species (5NSC, 1997; Lindeboom and de Groot, 1998). In addition, trawling effort is not homogeneously distributed. It has been estimated that some areas of the bottom are visited more than 400 times per year, and others not at all (Rijnsdorp *et al*., 1996).

Estimates of the area of bottom and macrobenthos affected by trawling activity in relation to gear type are given in *Table 5.6*. Recent studies suggest that beam trawls are among the most damaging to benthic communities (Lindeboom and de Groot, 1998).

The effects of disturbance by fisheries appear to be related to the background level of physical disturbance of the region in the absence of trawling and the size of the benthos. Areas of relatively low natural disturbance typically show greater effects. Whilst the effects of fisheries on larger benthos are consistent, both increases and decreases have been reported in the abundance of small invertebrates in the aftermath of trawling (Lindeboom and de Groot, 1998). In some near-shore cases fishing has led to loss of target populations and changes to the physical structure of the habitat.

Most *Sabellaria* reefs in the German Wadden Sea have disappeared. This may be due to fishing activities and the subsequent sediment disturbances caused by trawling and dredging. Recovery may be possible in closed areas (De Jong *et al*., 1999). Cold water coral reef systems near Norway are also affected by demersal fisheries.

The number of mature mussel (*Mytilus edulis*) beds in the Wadden Sea has declined over the last two decades due to fisheries, storms and ice coverage (De Jong *et al*., 1999).

Seabirds. Observations attest to the death of seabirds from entanglement in fishing gear. Evidence suggests that the heaviest impact is due to gillnets and other fixed nets that can entangle diving birds. The impact cannot be quantified at present but is thought to be sporadic and localised.

Increased food supply from offal and discards is a likely cause of some population increases (5NSC, 1997).

Table 5.5 Gear types used in the North Sea fisheries in 1996 in relation to target and by-catch species. Source: 5NSC (1997).

Gear Type	Fishery	By-catch
Demersal active gear		
Otter trawl: (human consumption fishery)	*Nephrops*, roundfish and some pelagic species	Unwanted sizes of target and non-target species of fish and other vertebrates
Otter trawl: (industrial fishery)	Small fish species (sandeel, Norway pout, sprat)	Human consumption fish
Demersal seines: single and pair	Human consumption fish species (roundfish and flatfish)	Unwanted species and sizes of fish
Beam trawl: light nets equipped with bobbins	Brown shrimp	Flatfish and benthic invertebrates
Heavy gear equipped with chaines	Flatfish (sole and plaice)	Juvenile target species, non-target fish and benthic vertebrates
Dredges	Molluscan shellfish	Flatfish, damage to target and non-target benthic species
Pelagic active gear		
Purse seines, pelagic trawl, single and pair	Shoaling pelagic species (herring, mackerel and sprat)	Low by-catch of non-target species. Unmarketable* fish released dead or damaged
Passive gear		
Nets: gill nets, demersal set nets, drift nets	Human consumption fish species (cod, turbot and other species)	Seabirds, harbour porpoise (for which gillnet is the main source of by-catch)
Traps: portable baited traps and coastal trap nets	Crustacean shellfish and salmonids	Undersized and non-target shellfish
Lines: long lines and hand lines**	Deepwater demersal fish	Seabirds

* Non-commercial or undersized commercial species; ** Little used in the North Sea.

Table 5.6 Effects of different types of fishing gear – extent of seabed disturbance and affected species. Source: 5NSC (1997).

Gear type	Penetration depth	Species affected	Area affected*
Otter trawl (pair and twin)	Ground rope, bobbins chains: < 5 cm (soft bottom) < 2 cm (hard bottom) Trawl door: 6-20 cm (soft bottom)	Epifauna (e.g., crustacea: *Corystes* and *Eupagurus;* Molluscs: *Abra alba, Arctica islandica, Donax vittatus, Spisula subtruncata, Placopecten;* echinoderms: juvenile *Echinocardium, Psammechinus miliaris;* cnidaria, hydroids, *Alcyonium digitatum*)	99 000 km^2 (1989 – covers entire North Sea area where otter trawl was used)
Beam trawl	Chains: 4-8 cm (soft bottom) 3-6 cm (hard bottom) Trawl heads: 7-10 cm Combined effect of beam trawling in other areas: < 10-20 cm deep tracks noted.	Same epibenthic fauna as otter trawl, but in addition: *Pectinaria* spp. *Aphrodita aculeata,* sipunculids and tunicates, molluscs: *Tellimya ferruginosa, Turitella communis, Chamelea gallina, Dosinia lupinus, Mactra corallina.*	323 000 km^2 ** (1989 – central and southern North Sea)
Demersal pair trawl	Ground rope: 1-2 cm	Same as for otter trawl	108 000 km^2 (1989 – covers entire North Sea)
Twin trawl	Same as for otter trawl but without door	Same as for otter trawl	
Seines and ring nets	Zero	Minimal effects on benthos	245 km^2 (covers entire North Sea)
Pair seine	See seines and ring nets	See seines and ring nets	
Dredges	Mussel dredge: 5-25 cm Cockle dredge: 5 cm Scallop dredge: 3-10 cm	See beam trawl. Use of multiple scallop dredges markedly increases the swept area.	Estuarine and coastal areas of the North Sea
Shrimp beam trawl	Bobbins: 2 cm	In addition to benthos killed in trawl path there is a high mortality of benthos and juvenile fish in small-mesh nets	Estuarine and coastal areas of the North Sea
Prawn trawl	See shrimp beam trawl	See shrimp beam trawl	Northern North Sea
Industrial trawls	See otter trawl	Epibenthic fauna (see otter trawl)	Industrial pair trawl: 11 000 km^2 (central North Sea). Industrial single trawl: 127 000 km^2 (entire North Sea)

* Areas affected by fishing gears may overlap;
** Recent information indicates that 171 000 km^2 of the area between 51° N and 60° N is fished by the Dutch beam trawl fleet, which constitutes about 80% of the total beam trawl effort in the North Sea (Rijnsdorp *et al*., 1997).

Seabirds are estimated to consume approximately 50% of all the material discarded annually (Camphuysen *et al*., 1993) amounting to 109 000 and 71 000 t of discards and offal respectively. Fisheries may also compete directly for seabird prey. In this context concern has been expressed about possible adverse effects of industrial fisheries, particularly those for sandeel, and also those for Norway pout and sprat (similar concerns have been expressed with respect to other fish species and marine mammals which also consume sandeels). In 1999, ICES documented evidence of a negative effect of sandeel fisheries on the breeding success of seabirds only for the North Sea off Scotland. Kittiwakes (*Rissa tridactyla*) were notably affected because of their dependence on sandeels during the breeding season. The S*pisula* fishery has decreased the food available for the common scoter. Eider ducks and oystercatchers (*Haematopus ostralegus*) in the Wadden Sea have suffered recently from human over-exploitation of the mussel and cockle stocks. Discards and offal from fisheries may maintain certain seabird populations at higher than natural levels, although direct evidence for this is lacking (Hüppop and Garthe, 1995).

Marine mammals. Most bycatch problems involving marine mammals appear to involve small cetaceans rather than seals. Harbour porpoise are the most common fishery bycatch. Most are caught in bottom-set gillnets. Estimates yield an annual bycatch of more than 7000 animals per year (IWC, 1996). This estimate exceeds 2% of porpoise abundance. Any bycatch rate in excess of approximately 2% of population abundance is likely to be un-sustainable. Taking into account abundance estimates, estimated bycatch, and harbour porpoise biology, it is likely that the current bycatch alone poses a significant risk to the population. Data from Danish and US experiments have shown that porpoise bycatch might be greatly reduced by use of appropriate acoustic deterrents or 'pingers'.

5.3.5 Impact of mariculture

Concern over the potential impact of mariculture on the marine environment focuses on the degradation of benthic communities around farms due to increased deposition of organic matter, the use of chemicals and their potential impact on coastal waters, the possibility of eutrophication by nitrogen and phosphorous from fish cages, and genetic disturbance.

Genetic disturbance

In the North Sea region there has been concern regarding genetic disturbance of natural populations due to contamination from mariculture and salmon restocking and ranching operations. Although cultured stocks were of course initially based on wild stocks, selection has led to some differentiation in the genetics of cultured animals. Genetic effects of mariculture on wild stocks is an issue mainly concerning Atlantic salmon, and escaped salmon have been found to make up more than 50% of the individuals in several rivers in Norway where the natural stocks are low. At present both genetic differences between cultured and wild stocks and the number of escapees from mariculture give reason for concern. However, on escape, cultured animals tend to be outcompeted by wild stocks.

Chemicals, disease and parasites

Pesticides and antibiotics are used to protect farmed fish along the North Sea coasts of Norway and Shetland. The effects of pesticides, such as the inhibition of acetylcholinesterase in mussels by dichlorvos, are reported to be very localised. Most of the antibiotics used are persistent in the environment, and spread from the farms to surrounding areas, where accumulation in sediments may occur. Recent data suggests antibiotic resistant bacteria evolve rapidly in the vicinity of fish farms (see section 4.6.1). Microbial floras under European fish farms do not appear to include pathogens. Antibiotic residues have only been detected in marine invertebrates growing directly on fish cages. Fish species, such as mackerel, that occasionally scavenge fish farm wastes show very low concentrations of antibiotics.

Both external and internal parasites may cause problems on wild fish stocks. Various species of lice are reported on Atlantic cod and other white fish species. Salmon lice have been found in large numbers on wild Atlantic salmon and on sea trout, with sea trout populations apparently especially heavily infected. This may be one reason for the observed decrease in populations of sea trout and salmon in Norwegian waters.

5.3.6 Impact of eutrophication and organic loading (nutrients, oxygen)

Algal blooms, oxygen depletion and the effects on fauna

'Eutrophication effects' are effects resulting from nutrient enrichment. Among these are increased levels of nutrients during periods when production is low followed by increased production and biomass of phytoplankton. Additionally, there are changes in species composition including the occurrence of harmful algae, changes in benthic algal and animal communities, and changes in oxygen consumption in water and sediments.

There is some evidence that changes in nitrogen to phosphorus ratios can effect species composition and food web structure and these remain a strong, causal candidate for observed algal community changes. However, additional evidence is required to demonstrate that changing rates of nitrogen and phosphorus input have had an effect on the North Sea ecosystem.

An important question related to eutrophication concerns the response of the ecosystem to reduction of nutrient input. Results from an OSPAR Workshop in 1996 on 'Modelling Eutrophication Issues' indicated that a 50% reduction of riverine input of nitrogen and phosphorus would incite a reduction in the response of the ecosystem but that this reduction would be less than 50% and it would be geographically variable. These modelling results are to some extent reflected by observations in the Wadden Sea following reduction of the input of inorganic phosphorus to that area.

Comparison of Dogger Bank macrofaunal communities from 1987 and 1996 showed several changes. Eutrophication may have been a factor in these changes in addition to the effect of the cold winter 1995/6 and changes in hydrography.

Organic enrichment of deeper water and sediments with additional organic detritus leads to an increase in macrobenthic biomass, but only until anoxia develops here and consequently benthos die.

Anoxic conditions have also been reported for intertidal habitats. Small black patches of intertidal surface sediment indicative of anoxia have been observed in the German Wadden Sea and appear to have increased in frequency since 1984. The burial of organic material (mainly macroalgae) is primarily responsible for the occurrence of these black spots. In the spring of 1996 sudden large anoxic areas of sediment were observed in the East-Frisian part of the Wadden Sea area of Lower Saxony spreading to 36 km^2 by June. The anoxia was accompanied by mass mortality of the benthos. An analysis led to the hypothesis that the black areas were the result of an unusual juxtaposition of meteorological and biological events. The main determining elements were a cold winter favouring the early blooming of *Coscinodiscus concinnus* in the adjacent North Sea and landward currents transporting large amounts of organic material from the bloom into the Wadden Sea (De Jong *et al*., 1999).

5.3.7 Impact of recreation and tourism

Recurrent disturbances relating to recreational activity may make specific areas unsuitable for feeding, resting and breeding for birds and marine mammals, but are unlikely to affect marine organisms over a wide scale. The tourist season coincides with the breeding season for both birds and seals. Bird breeding areas on sandy beaches have been almost completely lost due to human recreation.

These disturbances have complicated effects on the energy budgets, survivorship and breeding success of birds.

Some beach habitats such as primary dunes are very important for a number of breeding birds. However, many of these sites are used for human activities and thus not available as breeding sites. Little tern (*Sterna albifrons*) and kentish plover (*Charadrius alexandrinus*) are most strongly affected by this, as their breeding success is reduced by human activities.

While in the past almost all curlews (*Numenius arquata*) left the Danish part of the Wadden Sea during the hunting season, there has been a remarkable increase in numbers of this disturbance-sensitive species after the hunting of curlews was banned in Denmark.

5.3.8 Impact of sand and gravel extraction

Sand and gravel extraction takes place most intensively in the southern North Sea. Extraction results in sediment disturbance in addition to sediment removal. Not all of the sediment extracted from the sea is retained on board the extraction vessel. A proportion of it is returned to the sea causing a localised transitory turbidity plume. The surface of the seabed may be covered with the returned material to the possible detriment of benthic organisms outside the dredged area. Benthic effects result from sediment removal and transport as well as the settlement of resuspended material. Extraction has resulted in an 80% reduction in benthic biomass and complete recovery following cessation of extraction activities may take from 1 month up to 10 years or more. Shorter recovery times are possible in more dynamic sea areas.

In the Wadden Sea, extraction has had a much greater impact on intertidal and shallow gully areas than in deeper gullies. Extraction sites refilled very slowly, and the bottom fauna were not fully restored after 15 years. Large, long-lived bivalves were particularly affected.

In The Netherlands sand and gravel extraction is not allowed landward of the 20 m depth contour due to the importance of maintaining undisturbed sand transport dynamics near the coast. Field studies have confirmed the establishment of opportunistic (polychaete) species within one year and the lack of recovery of long-lived species (bivalves) up to 2 years after extraction (Van Dalfsen and Essink, 1997).

5.3.9 Impact of dredging and dumping of dredged materials

In estuarine systems periodic removal of local shallow water sediments by dredging may change the tidal flow regime as well as the erosion-sedimentation cycles. Apart from effects of contaminants that may be present in certain dredged sediments, dumping of dredged material will influence suspended matter concentrations and nutrient dynamics on and near dumpsites, especially in estuarine systems. Increased suspended matter concentrations are known to affect both plants and filter-feeding organisms. Increased turbidity affects vision-reliant predators. At dumpsites, benthos will be affected directly by dumped sediment. The risk of burial and death is strongly dependent on the abilities of benthic species to escape by burrowing upward to restore contact with the sediment-water interface. Bivalves are among the most susceptible to sediment deposition. Extensive literature data, together with results of a case study in the Ems estuary, indicate that negative effects of dumping on macrozoobenthos will be limited so long as the deposition thickness is less than 20 – 30 cm (Essink, 1993; 1997).

The habitats in the Western Scheldt are very much under influence of the increasing volume of maintenance dredging for shipping. As a consequence of the progressive deepening of the main tidal channels for shipping, salt marshes and high mudflats are eroding and the extent of shallow water nursery areas for flatfish and shrimp have decreased (Vroon *et al*., 1997).

5.3.10 Impact of coastal protection and land reclamation

Construction activities related to coastal protection and land reclamation often result in destruction or changes in habitat size and resultant effects on ecological processes. This type of impact is prevalent along the North Sea coast and tends to be greatest in the southern regions. Impacts fall under the categories of extraction of bottom material, dumping and disposal, construction-related changes in current regimes, human presence (recreation) and noise.

Various North Sea habitats have been disrupted by human construction activities, especially by measures attempting to physically protect and stabilise the land-sea boundary. For example, the Dutch coastline has been greatly affected, causing the disappearance of very many natural transition zones between freshwater habitats and coastal waters. Growing awareness has recently led to attempts to restore such lost transition zones. These restorations include both relatively small efforts (e.g. fish migration facilities in pumping stations which are designed for discharging excess freshwater), and large ones (e.g. gradually opening the sluices of the Haringvliet to the extent that the tidal flow of seawater is allowed to re-enter the area).

The construction of the storm-surge barrier in the mouth of the Eastern Scheldt that was completed in 1986 caused many changes to the functioning of this former estuary (Nienhuis and Smaal, 1994). Intertidal habitat decreased in height and area due to redistribution of sediment, a process that is continuing. As a consequence, fewer waterfowl are anticipated to feed on the intertidal flats in the future (Van Berchum and Wattel, 1997).

In the light of increasing sea levels, future coastal protection policies will have to address the question of how to guarantee sufficient protection in a way that is compatible with nature protection needs.

5.3.11 Impact of offshore oil and gas activities

Drilling activities

Data indicate that biological changes are detectable in benthic communities up to 5 km from the drilling sites, but usually not further than 3 km (Gray *et al*., 1999). This is due mainly to the discharge of drilling wastes and cuttings. It has been reported that major changes extend to a maximum of 500 – 1 000 m from the drilling source.

Toxicological effects of water-based drilling muds on fish have not been observed. A small proportion of flatfish in the vicinity of some North Sea platforms have been found to be tainted. Dilution of the discharge plume within 1 000 m of the platform appears to render the tainting risk negligible (GESAMP, 1993).

Two types of adverse effects of discharges of cuttings can be distinguished: physical smothering and chronic toxicological effects on the benthos. These effects include reduction in a number of sensitive species, increase in abundance of some opportunistic species, increased mortality, overall reduction in macrobenthos abundance, and reduced macrobenthic diversity.

Production discharges

In contrast to drilling discharges, environmental data on the impact of produced water are very limited. Several studies have demonstrated accumulation of hydrocarbons from produced water in marine organisms. The concentration of toxic compounds in most produced waters are well below individual species 96 h LC_{50} values (suggesting no acute toxicity beyond the immediate vicinity of the discharges) but LC_{50}s are very species specific and only cover short-term, acute effects. There is very little data for sublethal and chronic effects, such as endocrine disruption.

Monitoring of both chemical concentrations and biological effects at offshore sites should continue in order to strengthen the database regarding long-term ecological change in the peripheral zone surrounding the platforms. Produced water PAHs may also bioaccumulate in organisms. The nature and scale of impacts from the process of flaring need to be established (GESAMP, 1993).

Recent field experiments in the Tampen area on the Norwegian shelf have shown significantly increased levels of PAHs in caged mussels and passive samplers up to 10 km away from the nearest produced water discharge sites. The levels in mussels ranged from 2.5 – 140 times the local background concentrations depending on their distance from the site of discharge (Roee *et al*., submitted).

Construction and decommissioning

The construction of pipelines and other offshore developments creates artificial hard-bottom substrates to which a large variety of organisms attach. These hard bottom communities may increase the biological diversity locally but are not considered to affect either the large scale community structure or the food web structure of the Greater North Sea.

To date all platforms that were removed have been reused or disposed of on land and therefore there is no information on the impact of abandonment at sea.

5.3.12 Impact of shipping

The three most important impacts related to shipping are introductions of non-indigenous species, the effects of antifouling substances, and spills and discharges of oil and other substances.

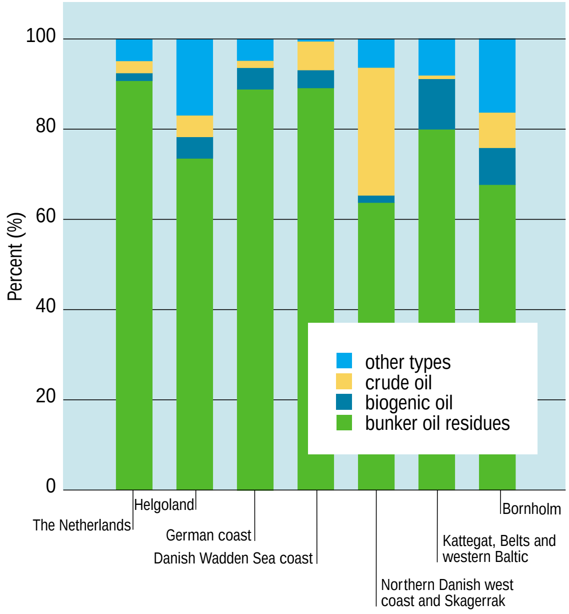
Many organisms carried within ballast water (see section 5.3.1) are killed either in transit or when ballast water is discharged. Some, however, survive and can be a threat to native species. Another important impact of shipping is related to the contamination caused by the use of TBT (see section 5.3.13) and other antifouling agents.

Imposex affected female common whelk, dog whelk and red whelk (*Neptunea antiqua*) are now extremely common in the North Sea and Baltic region in contrast to the situation before 1978, when no imposex was found in samples from the same areas (ten Hallers-Tjabbes, 1979; Foelsvik *et al*., 1998). Offshore occurrence of imposex in prosobranch gastropods is correlated with shipping traffic intensity (Ten Hallers-Tjabbes *et al.*, 1994).

Birds are the most obvious victims of oil slicks (Skov, 1991), but marine mammals can also be fouled. In the 1993 QSR it was reported that each year tens of thousands of seabirds die as a result of oil slicks. Other lipophilic substances can form sheens on the sea surface and have led to bird deaths. Beached bird data has been used to monitor the trend and relative impact of oil pollution in the North Sea. The proportion of oiled specimens among beached seabirds can be used as an indicator of oil discharged into coastal areas surrounding patrolled beaches, especially when linked to chemical analyses (i.e. 'fingerprint analyses') of the sources of pollution. Chemical analyses of both beached birds and contaminated beaches studied under the Oiled Seabirds project indicate that the source is primarily discharged bunker oil residue from shipping *(Figure 5.11)*. However, 32% of the samples on the Skagerrak coast involved crude oil. Within IMO measures have been taken to reduce these discharges (MARPOL 73/78 Annex I) but these discharge practices still appear to be quite widespread (Skov *et al*., 1996) and some of these exceed the IMO legislation. The relative vulnerability of different seabird species is reflected in their proportion of oiled corpses *(Table 5.7)*.

Recent analysis of data from beached-bird surveys conducted since 1969 in The Netherlands has shown that oiling rates of beached birds have declined significantly over the last 30 years. Several coastal species showed distinctly lower oiling rates in the Wadden Sea than along the North Sea coast, suggesting that the risk of oil contamination is much less in the Wadden Sea. In contrast, pelagic birds found beached within the Wadden Sea were oiled to the same extent as those found along the North Sea coast, suggesting that these birds only enter the Wadden Sea when already weakened from oil exposure.

Figure 5.11 **The proportion of the main sources of oil collected on beaches and birds in the regions under the Oiled Seabirds project.**



The decline in oiling rates among beached birds began in the early 1970s and the gradual implementation of MARPOL Annex I may have assisted the trend. The Dutch results clearly indicate a decrease in the level of oil pollution in the southern North Sea and in the Wadden Sea in particular. However, the oiling rates found in The Netherlands are still rather high in comparison with relatively clean areas such as the Shetland Islands.

Measurable declines in the proportion of oiled birds have taken place in the other observed regions of the North Sea, except along the west coast of Denmark between Nymindegab and Skagen, where the relatively constant, high proportion of oiled corpses has not changed since 1985 (Skov *et al*., 1996).

Table 5.7 The vulnerability of different seabird species to oil pollution in Danish waters as reflected by the proportion of the total number of corpses with oil pollution. Source: Skov *et al*. (1996).

	total number of corpses 1984–95	percentage with oil
coot (*Fulica atraarra*)	228	16
black-headed gull (*Larus ridibundus*)	555	16
mallard (*Anas platyrhynchos*)	358	19
shelduck (*Tadorna tadorna*)	382	22
great black-backed gull (*Larus marinus*)	261	23
herring gull (*Larus argentatus*)	1310	24
swans (*Cygnus* spp.)	911	24
common gull (*Larus canus*)	741	28
goldeneye (*Bucephala clangula*)	76	34
tufted duck (*Aythya fuligula*)	49	39
eider (*Somateria mollissima*)	2141	42
red-breasted merganser (*Mergus serrator*)	65	43
kittiwake (*Rissa tridactyla*)	893	48
gannet (*Sula bassana*)	95	65
guillemot (*Uria aalge*)	2695	67
puffin (*Fratercula arctica*)	85	67
fulmar (*Fulmarus glacialis*)	85	67
velvet scoter (*Melanitta fusca*)	197	68
common scoter (*Melanitta nigra*)	1296	72
divers (*Gaviidae* spp.)	192	73
grebes (*Podiceps* sp.)	242	75
little auk (*Alle alle*)	261	84
razorbill (*Alca torda*)	707	87

In contrast to data obtained from the Danish west coast, measurable declines in the proportion of oiled birds have taken place in the other observed regions of the North Sea. Declining trends have also been observed for the Danish part of the Wadden Sea.

5.3.13 Impact of contaminants

Since most contaminants enter the North Sea by riverine outflows or run-off from surrounding land, in particular via rivers, the highest concentrations and greatest consequences are often found in coastal areas. Additional inputs come from sources at sea (ships, offshore platforms, dumping of dredged materials) and via the atmosphere.

After entering the sea, contaminants are usually diluted and widely dispersed. Nevertheless, adsorption onto suspended particulate matter in the sea tends to concentrate particle-reactive contaminants and leads to elevated concentrations in depositional areas (e.g. Dogger Bank, Oyster Ground, Wadden Sea, German Bight, Skagerrak and Norwegian Trench). These concentrations increase the likelihood that effects will be detected more frequently in such areas than elsewhere (NSTF, 1993).

Eutrophication, through increased sedimentation of organic matter, may further increase delivery of toxicants to sedimentary ecosystems (Longva and Thorsnes, 1997; Hylland *et al*., 1997). As a result, sediments occur in several regions that are toxic to invertebrates and cause physiological responses in fish. Some examples of lesions and ulcerations in dab thought to be caused by contamination are shown in *Figure 5.12*. Recent trends in the prevalence of lymphocystis, epidermal papilloma and skin ulcers in North Sea dab are depicted in *Figure 5.13*.

Another important process is bioaccumulation of contaminants in the tissues of organisms *(Figure 5.14)*, determined by the biological availability, the metabolism and the excretion of the contaminant or its metabolites. Similar levels of a specific contaminant can have different effects since it may be present in different chemical forms which are differentially available to organisms. Bioaccumulation can lead to a risk to all consumers including human beings.

The ecological effects of contaminants are often very difficult to assess. With the possible exception of some organotin compounds, no data are available for the direct cause-effect of individual compounds or elements in the North Sea. Therefore field data from other environments or the results of laboratory testing must be used for assessments. Laboratory experiments give only limited information in relation to the natural environment due to both the complexity of nature and the presence of multiple contaminants in the environment. For these reasons subtle ecological impacts, for instance the endocrine disruption effects of some organic contaminants, are often very difficult to discern. However, recently developed longer-term (ca. 5 months) experimental approaches using intact communities make detection of more subtle, ecologically-relevant impacts possible (Dahllöf *et al*., 1999; see section on TBT).

To allow some degree of assessment of environmental concentration data 'Ecotoxicological Assessment Criteria' (EACs) were derived from available toxicity data (OSPAR 1997). While based on laboratory toxicity tests, usually employing freshwater organisms, these reference values were established for use as the best available assessment criteria. Levels below these values suggest that no harm to the marine environment should be expected. EACs for the most important contaminants in the North Sea are reported in Chapter 4 where they are related to measured concentrations in selected biota.

Impact of trace metals

Due to the difficulty of differentiating specific biological effects of particular contaminants from confounding

Figure 5.12 **Three examples of diseases of the common dab from the North Sea: (a) lymphocystis, (b) epidermal papilloma; (c) ulceration.**

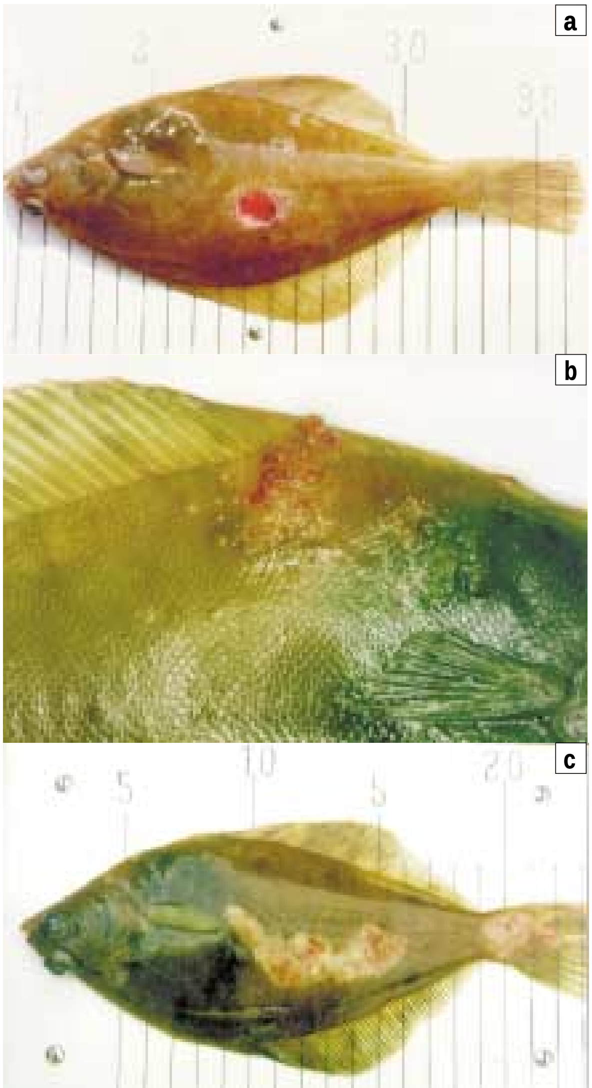
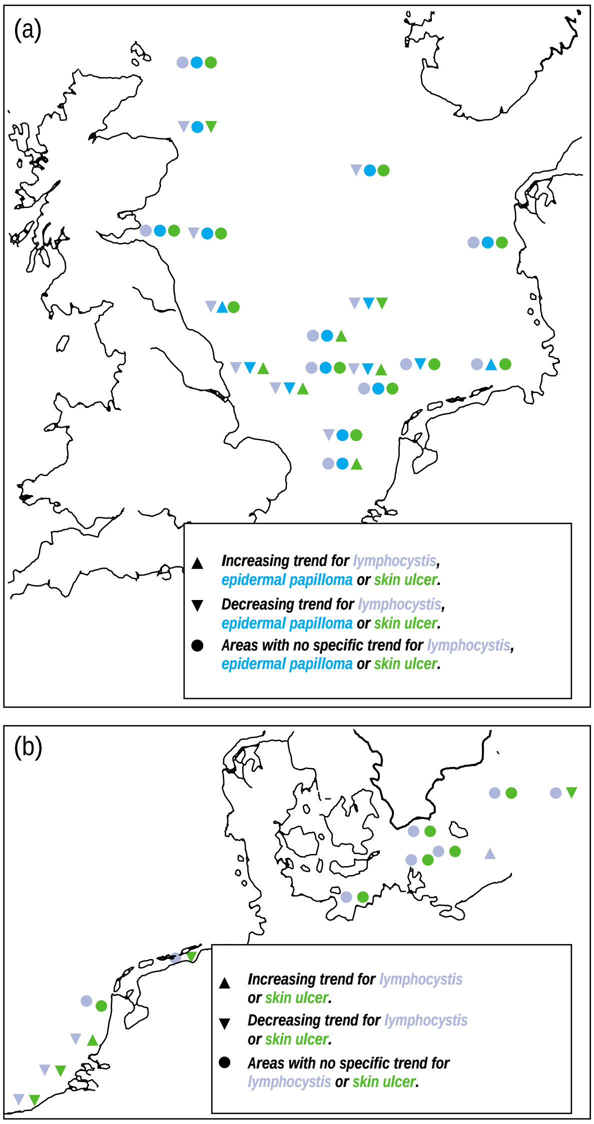


Figure 5.13 **Recent developments (since 1992) in the prevalence of lymphocystis, epidermal papilloma and acute/healing skin ulcer in (a) common dab and (b) in flounder.**



factors in the field, no direct effects of trace metals have been observed on North Sea biota. Nevertheless, the fact that EACs for a number of metals are exceeded in certain areas (see Chapter 4) suggests that biological effects are possible and may indeed be occurring. One should, however, not forget that ecotoxicological data for trace metals do not (yet) take into account that due to adsorption and the formation of complexes, only part of the total metal content may be bioavailable.

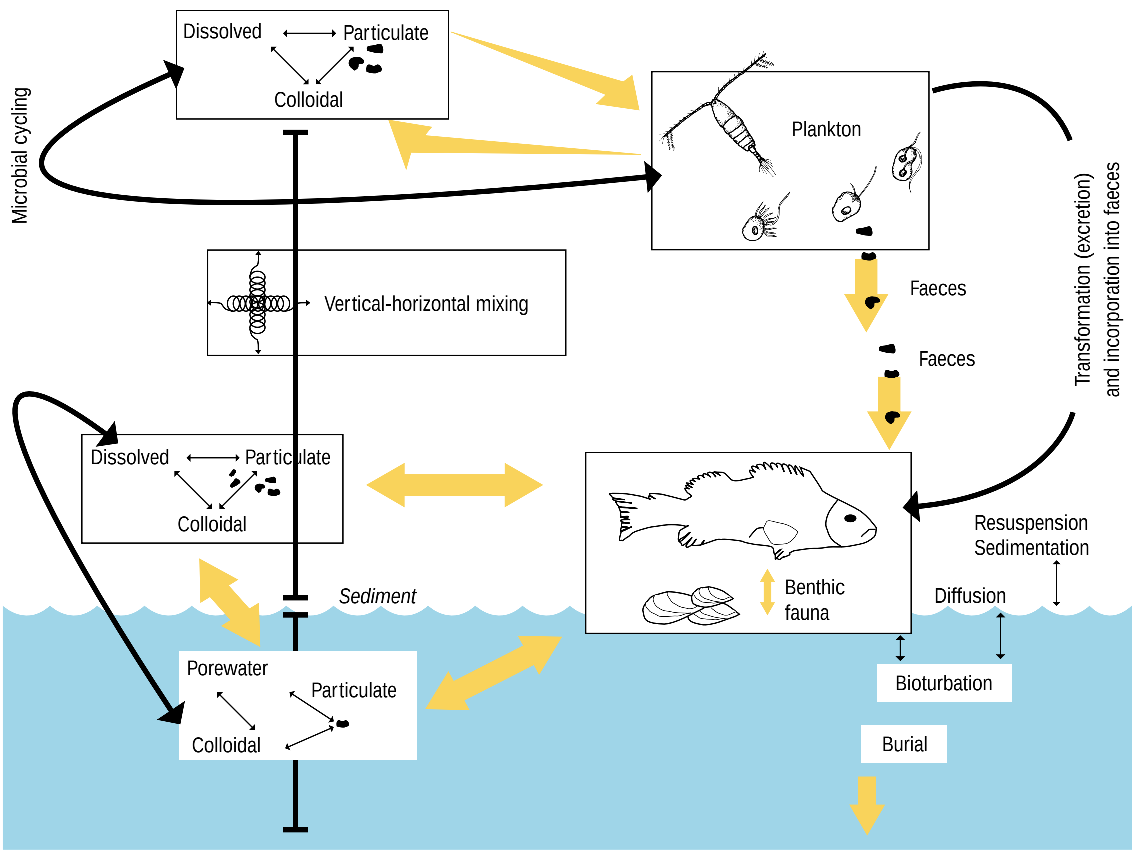
In general, risks to the ecology of the North Sea from metals appear to stem from copper contamination, (mainly due to effects on the production at lower trophic levels such as bacteria and phytoplankton), cadmium and mercury (on top predators) and lead (on predators of shellfish). These effects are expected to occur most frequently in estuaries and in the coastal zone. They are due in large part to the tendency of these metals to bioaccumulate in organisms through trophic interactions.

Although the present EACs are a first step towards a system for interpreting (elevated) environmental concentrations of contaminants, there is an urgent need to further improve the EACs presently in use and to develop other additional assessment criteria.

Impact of organic pollutants

Information on which compounds are occurring and at what concentrations, let alone their effects, is scarce for the North Sea. This is illustrated by the often very low

Figure 5.14 **Bioaccumulation and cycling of particle-reactive persistent contaminants. Source: Hagström *et al*. (1996).**



proportion of positively identified compounds of the total extractable organochlorines and organobromines from sediments. Many of the (synthetic) organic compounds appear to degrade in the environment, but others degrade only very slowly, if at all. Any additional ecological harm caused by these chemicals will be strongly dependent on local geochemical conditions and bioavailability. From time to time a qualitative chemical screening needs to be conducted at suitable locations in order to identify any newly occurring hazardous substances in the marine environment. Such substances should then be addressed in accordance with the requirements of the OSPAR Strategy with regard to Hazardous Substances.

Copepods have been shown to be sensitive to a wide variety of organic toxicants such as insecticides, organometals and oil. Field studies and mesocosm experiments (Jak and Scholten, 1994) as well as model simulations (Jak and Michielsen, 1996) have shown that negative effects on zooplankton may lead to increased phytoplankton densities due to reduction of grazing pressure. This was especially true for the insecticides lindane and mevinfos. These results suggest that apparent eutrophication effects such as increased phytoplankton biomass may also be due to the presence (at low concentrations) of contaminants in coastal waters.

Tributyltin (TBT). Compared to other metals and organic compounds there is a relative abundance of effect data for TBT. Exposure originating from anti-fouling paints produces distinctive responses. These include shell thickening in Pacific oysters and imposex in gastropods.

Imposex is a form of pseudo-hermaphroditism in which females develop non-functional penes and vas deferens. It has been observed, for example, in the prosobranch gastropods the common, dog- and red whelks (Ide *et al*., 1997). Severe imposex can lead to sterility and population-level effects. Effects are known to occur at very low exposure levels with no observed effect concentrations (NOECs) of 1 ng/l for dogwhelks.

TBT also affects other types of organisms, including phytoplankton, zooplankton (at levels less than 1 ng/l) and fish (reproduction 1 – 10 µg/l, behaviour 1 – 100 µg/l). Offshore incidence of imposex in prosobranch gastropods is correlated with shipping traffic intensity (Ten Hallers-Tjabbes, 1994). Recent data suggests that common whelks, and perhaps other affected species, are vulnerable to TBT effects primarily as juveniles (Mensink *et al*., 1996). Experiments with North Sea plankton communities in mesocosm enclosures suggested that TBT might also lead to increased phytoplankton biomass through reduction of zooplankton grazing, similar to effects seen for the pesticides noted above (Jak *et al*., 1998).

Organohalogens and PCBs. There is increasing evidence of links between concentrations of PCBs (and possibly other organic substances) and alterations of thyroid hormone metabolism and impaired reproduction in harbour seals in the Dutch Wadden Sea. It is not clear whether other North Sea seal populations have been affected. The evidence of a link with decreased resistance to disease is still inconclusive. However, it is important to note that relatively high concentrations of individual planar PCBs (greater than 100 µg/kg fat weight), which exhibit a dioxin-like toxicity, have been detected in seals from the North Sea (Brouwer *et al*., 1989).

Polycyclic aromatic hydrocarbons (PAHs). There is evidence of a correlation between the occurrence of liver tumours in North Sea flatfish and contaminants, particularly chlorinated hydrocarbons and PAHs. An additional potential risk includes uptake and accumulation of PAHs by deposit-feeding benthic invertebrates which have a well-developed ability to digest and absorb particle-bound organic contaminants including PAHs and thus form the basis of a food chain leading from bottom-feeding fish to humans and other top predators (Forbes and Forbes, 1997).

Effects of endocrine disrupting chemicals

Studies in the UK have shown that a number of surface waters receiving effluents from sewage treatment plants induce oestrogenic effects in fish. Observed effects include production of vitellogenin and reduction in testicular growth (Harries *et al*., 1997). The oestrogenic activity was due to the presence of natural hormones (17-beta oestradiol, oestron) and, to a lesser extent, to synthetic hormones deriving from the use of birth control pills (17-alpha ethynylestradiol) (Desbrow *et al*., 1998).

Flounder captured in UK estuaries were found to be less sensitive with respect to vitellogenin induction than salmonid species (Allen *et al*., 1999). For the North Sea estuaries, moderate levels of vitellogenin induction were found in the inner Thames, while low or negligible levels of induction were observed in the rivers Humber, Tamar, Alde and Crouch. High levels of induction were observed in the Tees estuary, that receives inputs from several chemical manufacturers (including the oestrogenic nonylphenols), and in the Tyne estuary. In the latter estuary intersex was observed in up to 20% of the flounder population.

Oestrogenic effects of reduced severity were also observed at offshore flounder spawning areas in the Southern Bight (Allen *et al*., 1997). The effects on the offshore spawning populations of flounder are likely to be due to exposure to oestrogenic compounds in estuaries. However the possibility of contamination in the open sea cannot be excluded.

The observed decrease in age at maturation of North Sea plaice and sole (Rijnsdorp and Vethaak, 1997) and anomalies in the sex ratio of North Sea dab (Lang *et al*., 1995) are unlikely to have been caused by specific contaminants. However, the significance of phenomena such as intersex and increased vitellogenin levels for the reproductive output of fish populations deserves further research.

Combined effects

Given that the impact or magnitude of contaminant effects can be quantified with available ecotoxicological techniques (see below), the next step in an assessment will often involve identification of the causes (AMAP, 1999). One method for reducing the list of possible causative agents is based on knowledge of local activities and/or environmental contaminant levels.

The effects of contaminants on the ecosystem can be very difficult to assess, but in recent years a number of biological effect testing methods have been recommended for biological monitoring (AMAP, 1999; ICES, 1997a). Effect measurements have the potential to be more cost effective than contaminant measurements but it is important to ensure that they measure what is needed to manage on a rational basis and preferably over a long period of time. A number of effects testing methods in use today have been recommended for biological monitoring at national and international levels (ICES, 1997a).

Biological effects components of the JAMP are expected to be fully implemented when quality assurance procedures have been developed. Methods currently in use include the oyster embryo bioassay, whole sediment bioassays (using the lugworm (A*renicola marina*) and an amphipod (*Corophium volutator*)), several more or less chemical specific biomarkers (e.g., acetylcholinesterase inhibition, metallothionein induction, vitellogenin induction), incidences of fish diseases (especially liver tumours in dab) and measurements of ethoxyresorufin-O-deethylase (EROD) activity in flatfish to evaluate exposure to organic contaminants (Jones and Franklin, 1998).

Biological effects monitoring has been somewhat *ad hoc* to date, and comparisons between areas and over time have been difficult. Furthermore, interpreting the data produced in terms of an impact at the population or ecosystem level has not been attempted (ICES 1999c). The co-ordination of these methods at a convention wide level should be encouraged.

In coastal waters around the United Kingdom, which do not appear to be seriously impacted by contaminants, some industrialised estuaries contain waters and sediments which are having a variety of lethal and sublethal effects on fish and invertebrates. Most effects (with the exception of those caused by TBT) are being caused by mixtures of substances which are individually present at relatively low concentrations.

In the Sandefjord fjord in Norway lower activity of hepatic cytochrome P4501A in cod from the inner part of the fjord compared to open coast cod was possibly caused by enzyme inhibition by TBT and/or non-planar PCBs (Knutzen and Hylland, 1998).

Bio-assays of sediment toxicity at stations in the Skagerrak and Kattegat have been compared with reference sites near the Faeroe Islands. The results indicated that sampling sites close to Gothenburg are so polluted that harmful effects on the ecosystem probably occur (Magnusson *et al*., 1996). I*n situ* biomonitoring of roundnose grenadier (*Coryphaenoides rupestris*) in the Skagerrak/Kattegat showed that observed induced EROD activity may be due to PAH exposure (Förlin *et al*., 1996; Lindesjöö *et al*., 1996).

A statistical analysis of fish disease prevalence data taken from the ICES Environmental Data Centre has recently been carried out (ICES, 1999c). Spatial and temporal trends of the major diseases of common dab and flounder were established. In general, stable to decreasing trends in prevalence dominated in the period 1992-96/7 (see ***Figure 5.13***). The only disease which increased in a considerable number of areas is acute/healing skin ulcers of dab. However, this disease occurs at a low prevalence in most areas. In addition to the establishment of these general trends, the results of the analysis help to identify areas of concern. Examples are the Dogger Bank, where exceptionally high prevalence of skin ulcers in dab has occurred since 1990, and the German Bight, where an increasing prevalence of epidermal hyperplasia/papilloma in dab was observed. A holistic data analysis by ICES providing information on cause-effect relationships between diseases and environmental factors will be part of future work.

A number of chemical fractionation techniques are also available to help identify and characterise toxicants in complex mixtures. One such technique is ‘toxicity identification evaluation’ (TIE) (USEPA, 1991). This is often combined with transport models or chemical fingerprinting techniques to identify the source(s) of the causative agent(s). The results of this combination of approaches can be used to develop management strategies and adjust management actions as necessary (AMAP, 1999).

5.3.14 Impact of marine litter

Very little information is available on the effects of litter. Recent estimates suggest that at least 600 000 m^3 of litter could presently be resting on the North Sea floor (see Chapter 3).

Entanglement and drowning of birds (especially gannets (*Sula bassana*) and fulmars (*Fulmarus glacialis*)), and marine mammals in lost fishing gear does occur, but the impacts at the population level are not known. A recent study in Helgoland found that around 3% of all living fulmars were tangled to some extent and 29% of fulmars found dead had been killed by entanglement in plastic. Birds can also be affected when they ingest small plastic particles, which has frequently been observed. In particular, the feeding behaviour of fulmars may be affected, since plastics are known to accumulate in the gizzard of this species. This phenomenon may have increased rapidly over the last two decades. Seabird chicks may also ingest small plastic items together with normal food when they are fed by regurgitation by their parents, and the items may be retained for long periods, owing to limited regurgitation by the chicks. Many birds use plastics to make their nests which chicks may ingest. In particular gannets build coloured nests. A study from The Netherlands found that the stomachs of beached fulmars contained on average 12 plastic objects and up to a maximum of 96.

Floating and drifting litter may be a vector for transoceanic or trans-regional movements of non indigenous species. Due to the present levels of litter, this merits attention.

5.3.15 Other impacts

The flow of several rivers in southern Norway has been altered as a result of impoundments for hydroelectric power development. This has changed the physical conditions of several fjords and also influenced primary production in the fjords. The fjords have a large storage capacity for fresh water and act as a buffer between freshwater outflow and coastal water. Therefore, it is difficult to observe any effect on the coastal water from the changed run-off pattern.

Activities such as shipping, offshore mining, and military use lead to mechanical, visual, and acoustical disturbances. Effects are uncertain. Observations in wildlife reserves in the Wadden Sea have led to the conclusion that air traffic (especially low flying, slow aircraft and helicopters) is a very frequent and serious disturbance factor. Seismic surveying in offshore oil exploration is not thought to have much effect on fisheries. However, fish more than 20 nautical miles away from the seismic vessel have been observed to move away from the explosion. In addition, airgun explosions have a lethal effect on fish eggs and larvae at a distance of some metres from the energy source. For these reasons seismic exploration is often prohibited at certain times of the year in areas where fish, such as herring, are known to shoal before spawning.