OSPAR Commission

for the Protection of the Marine Environment

of the North-East Atlantic

Quality Status Report 2000

Region II Greater North Sea

Quality Status Report 2000
Region II – Greater North Sea

Published by
OSPAR Commission, London 2000
ISBN 0 946956 48 0

Recommended reference format
OSPAR Commission 2000. Quality Status Report 2000, Region II – Greater North Sea. OSPAR Commission, London. 136 + xiii pp.

More information about OSPAR
The Convention for the Protection of the Marine Environment of the North-East Atlantic has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Union and Spain.

Visit the website at http://www.ospar.org

Illustration credits and copyrights

contents

4 Chemistry

FOREWORD

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention 1992) requires that Contracting Parties shall 'take all possible steps to prevent and eliminate pollution and shall take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected'.

To provide a basis for such measures, the Contracting Parties are required to undertake and publish at regular intervals joint assessments of the quality status of the marine environment and of its development. These assessments should also evaluate the effectiveness of measures taken and planned for the protection of the marine environment and should identify priorities for action.

The Ministerial Meeting at which the OSPAR Convention was signed also issued an action plan for the OSPAR Commission, with a commitment to prepare a quality assessment of the whole maritime area by the year 2000. A comprehensive quality status report on this scale has not previously been produced.

To implement these commitments the OSPAR Commission decided, in 1994, to subdivide the maritime area into five regions and to prepare, coordinated by the Environmental Assessment and Monitoring Committee, five detailed quality status reports. As a result, five regional task teams were set up to produce reports for the following areas (see inset in ***Figure 1.1***): Region I (Arctic Waters), Region II (Greater North Sea), Region III (The Celtic Seas), Region IV (Bay of Biscay and Iberian Coast) and Region V (Wider Atlantic). It was agreed that these reports should be developed in a scientifically sound manner and should be based upon an assessment plan and a scientific programme (covering monitoring, research and the use of assessment tools). It was also agreed that the information contained in the reports should reflect the outcome of the appropriate quality assurance procedures.

In 1995 the OSPAR Commission adopted a Joint Assessment and Monitoring Programme, to take over and build upon experience gained through its former Joint Monitoring Programme and the Monitoring Master Plan of the North Sea Task Force (NSTF).

The findings of the five regional quality status reports ('the regional QSRs') form the basis of a holistic quality status report for the entire maritime area (the 'QSR 2000'). This regional report is thus part of an overall quality status assessment for the North-east Atlantic in the year 2000. The QSR 2000 will represent an integrated summary of the quality status of the entire OSPAR maritime area and will both fulfil the commitment made by the parties to the 1992 Convention and provide a basis upon which the future work programmes of the Commission can be decided. In the Sintra Statement, which concluded the 1998 Ministerial Meeting of the OSPAR Commission, importance was attached to the outcome of the QSR 2000 as a basis for identifying and prioritising future tasks at the Ministerial Meeting of the OSPAR Commission to be held in 2003.

The term 'OSPAR Commission' is used in this report to refer to both the OSPAR Commission and the former Oslo and Paris Commissions. The 1972 Oslo Convention and the 1974 Paris Convention were superseded by the 1992 OSPAR Convention when it entered into force on 25 March 1998.

The conclusions and recommendations contained in this report draw attention to problems and identify priorities for consideration within appropriate fora as a basis for further work. Within its sphere of competence, the OSPAR Commission will decide what follow up should be given to these conclusions, recommendations and priorities for action. The rights and obligations of the Contracting Parties are not therefore affected by this report.

THE PARTICIPANTS

Framework

The Environmental Monitoring and Assessment Committee (ASMO) has overall responsibility for the preparation of periodic quality status reports, assisted by a working group, the Assessment Coordination Group (ACG). ASMO outlined the basic arrangements for the quality status reports in the Joint Assessment and Monitoring Programme (JAMP). Further scientific and technical arrangements were prepared by ACG. Regional Task Teams (RTTs) were set-up for each of the regions of the maritime area. The lead countries for the respective RTTs were responsible for providing logistical support to the RTT.

Information relating to the entire maritime area was prepared in 1996 – 1998 by the following OSPAR working groups: the Working Group on Inputs to the Marine Environment (INPUT), the Working Group on Impacts on the Marine Environment (IMPACT), the Working Group on Concentrations, Trends and Effects of Substances in the Marine Environment (SIME) and its Ad Hoc Working Group on Monitoring (MON). This information constituted the basis of the five regional quality status reports, and was supplemented by relevant national information as appropriate.

Regional Task Team for the Greater North Sea

The RTT for the Greater North Sea had primary responsibility for drafting this report. The Netherlands acted as lead country for the preparation of the report. In the period 1995 - 1999 the RTT comprised the following persons: Belgium: Willy Baeyens, Mia Devolder, Jasna Injuk, Pieter Joos, Martine Leermakers, Koen Parmentier, Georges Pichot, Jean-Pierre Vanderborght. Common Wadden Sea Secretariat: Folkert de Jong. Denmark: Thomas Forbes, Henning Karup, Mikkel Aaman Sørensen. European Commission: David Armstrong. France: Marcel Chaussepied. Germany: Hartmut Heinrich, Karin Heyer, Roland Salchow. The Netherlands: Hans Balfoort, Els de Wit, Lisette Enserink, Karel Essink, Frans Feith (Chairman), Kees Kramer (Technical Editor), Bob Oudshoorn (Secretariat), Jakolien Tijink, Tjark van den Heuvel, Frank van der Valk (Chairman), Carien van Zwol. Norway: Per Erik Iversen, Einar Svendsen. Sweden: Sverker Evans. United Kingdom: John Cotter, John Davies, Andrew Franklin, Richard Millner, Andrew Osborne.

The drafting of chapter 1 was co-ordinated by the United Kingdom, chapter 2 by Norway, chapter 3 by Germany, chapter 4 by Belgium, chapter 5 by Denmark and chapter 6 by The Netherlands. The drafting panels for these chapters, which were assited by RTT II members, comprised the following persons: Chapter 1: Andrew Franklin; Chapter 2: Einar Svendsen, Gerd Becker, Tjark van den Heuvel, Johan Rhode; Chapter 3: Karin Heyer, Roland Salchow; Chapter 4: Willy Baeyens, Jasna Injuk, Koen Parmentier, Jean-Pierre Vanderborght; Chapter 5: Thomas Forbes, Mikkel Aaman Sørensen, Henning Karup, Karel Essink, Richard Millner; Chapter 6: Lisette Enserink, Frank van der Valk, Bob Oudshoorn, Gerrit Baarse, Ton Kuik, Saskia Werners.

ACG and ASMO – representation by Contracting Parties

Chairmen of ACG: Ben van de Wetering (1994), Frank van der Valk (1995), Philip C. Reid (1996 – 1999).
Chairmen of ASMO: Georges Pichot (1994 – 1997), Roland Salchow (1998 – 2000).
Contracting Parties' delegates to ACG 1994 – 1999:
Belgium: Mia Devolder, Georges Pichot*, Wilfried Vyncke; Denmark: Jens Brøgger Jensen*, Henning Karup, Mikkel Aaman Sørensen; EC: Patrick McCutcheon*; France: Pascale Babillot, Marcel Chaussepied, Philippe Maire*, Jean-Marie Massin; Germany: Hartmut Heinrich*, Roland Salchow; Iceland: Helgi Jensson*; Ireland: Rick Boelens, Jacqueline Doyle*; The Netherlands: Lisette Enserink*, Frans Feith, Kees Kramer, Bob Oudshoorn, Folkert Post, Frank van der Valk, Carien van Zwol; Norway: Per Erik Iversen, Hein Rune Skjoldal, Rune Vistad*; Portugal: Antonio Macieira Antunes, Maria E.F. Avila Goulart, Graça Noronha, Irene Pereira, Joaquim Pissarra, Teresa Vinhas*; Spain: Victor Escobar, Pilar García, Argeo Rodríguez de León*; Sweden: Stig Carlberg, Sverker Evans*, Ingrid Jansson; United Kingdom: Mike Burn, John A. Campbell, Stephen Churley, Theresa Crossley*, John M. Davies, Andrew Franklin, Andrew J. Osborne, Philip C. Reid.
* also acting as Head of Delegation during ASMO(3) 1999 which adopted this report.

Observer organisations attending meetings of ACG and ASMO 1998 – 1999

Arctic Monitoring and Assessment Programme (AMAP), European Environment Agency (EEA), International Council for the Exploration of the Sea (ICES), Secretariat of the North Sea Conferences, Conseil européen des fédérations de l'industrie chimique (CEFIC), European Fertilizer Manufacturers Association (EFMA), Euro Chlor, World Wide Fund for Nature (WWF).

OSPAR Secretariat for ACG and ASMO (logistics, organisation, scientific and technical editing)

Stefan Hain (1994 – 1995), Carolyn Symon (1994 – 1998), Dornford Rugg (1998 – 2000), Gert Verreet (1995 – 2000), Ben van de Wetering (Executive Secretary 1995 – 2000).

Copy-editing: Dornford Rugg and Gert Verreet.

Technical support: Sylvie Ashe, Paula Creedon, Hélène Hughes, Corinne Michel, Barbara Middleton, Nicola Warden.

Design

Redhouse Lane Communications Ltd. (London).

OSPAR COMMISSION FOR THE PROTECTION OF THE MARINE ENVIRONMENT OF THE NORTH-EAST ATLANTIC

QUALITY STATUS REPORT 2000: REGION II – GREATER NORTH SEA

EXECUTIVE SUMMARY

Introduction

This report is one of five regional quality status reports prepared by the OSPAR Commission as part of its commitment to produce the first quality status report of the North-east Atlantic by the year 2000.

The report presents an assessment of marine environmental conditions and of its developments in that part of the maritime area of the OSPAR Convention which, for assessment purposes, is known as the Greater North Sea. The Greater North Sea is regarded as being bound by the coastlines of England, Scotland, Norway, Sweden, Denmark, Germany, the Netherlands, Belgium, and France, and by imaginary lines delimiting the western approaches to the Channel (5° W), the northern Atlantic between Scotland and Norway (62° N, 5° W), and the Baltic in the Danish Straits.

This quality status report assesses information collected until 1999 and aims to describe the present status and temporal changes that have been observed in the Greater North Sea, building on the 1993 QSR.

After the introductory chapter, the following topics are dealt with: geography, hydrography and climate (Chapter 2), human activities (Chapter 3), chemistry (Chapter 4) and biology (Chapter 5). Chapter 6 provides an overall assessment of the quality of the Greater North Sea.

Overall assessment

The general improvements that have been made and the means provided for continuing improvement, through the implementation of OSPAR strategies and other programmes, are reassuring. Inputs of heavy metals, oil from refineries and cuttings, and phosphorus have significantly decreased. In addition, the dumping of sewage sludge ceased in 1998 and the number of chemicals used in mariculture have decreased.

However, certain activities continue to give cause for concern because of their continued widespread impact or increasing trend, such as the impact of fisheries, inputs of nitrogen from agriculture, and inputs of oil and chemicals associated with increased quantities of produced water from offshore oil and gas. Concentrations of the antifouling agent tributyltin (TBT) still exceed safe levels in marina areas and biological effects remain a common phenomenon in the North Sea. An increasing number of synthetic compounds are being detected for which the ecological significance is not known. Though dredging impacts have diminished because of reduced contaminant loads, the quantities of dredged material are expected to increase in future, due to anticipated increases in the size of cargo vessels.

Human impacts are greatest in the coastal zones. Many sensitive habitats with large ecological significance are disturbed or vanish due to a range of activities. It is foreseen that there may be significant impacts due to demographic developments and climate change.

In conclusion, the intensive – sometimes conflicting – use of the North Sea causes a number of problems in relation to a healthy ecosystem and sustainable use. The ecosystems continue to suffer from a number of old problems, sometimes showing some signs of amelioration, but new problems have also arisen. The effects of hazardous substances, eutrophication, and the direct as well as indirect impacts of fisheries comprise the most important issues.

Main human pressures

To identify impacts of concern, human pressures on the North Sea environment have been ranked into four classes by using expert judgment, the results of which are shown in Chapter 6. The chapter focuses on the pressures of importance, supplying information on their impacts and the effectiveness of measures taken to reduce undesired impacts. Recommendations for future action are made for further consideration by the competent authorities. Although the impacts of the human pressures ranked in the lower priority classes are perceived to be less important, they may be of more serious concern in combination with other pressures. More information is provided in chapters 2 – 5.

Owing to the very broad scope of its causes and effects, climate change has the potential for significant impacts on the North Sea. It may influence factors in the North-east Atlantic which control the climate of Western Europe.

Human pressures on the North Sea were ranked in 4 priority classes.

First priority class

Fisheries

The main impacts of fisheries result from the removal of target species, from seabed disturbance by towed demersal gear and from the discarding and mortality of non-target species. Many target fish stocks are outside Safe Biological Limits.

These impacts are widespread and ecologically important and fully justify the further development and implementation of the ecosystem approach. Recommendations for consideration by the appropriate authorities are to continue efforts to reduce fleet capacity, the additional identification and use of closed areas which can protect juveniles and closed areas which are of conservation benefit through protecting benthos. The development of fishing gears which reduce or eliminate catches of non-target organisms and habitat disturbance is also encouraged.

Trace organic contaminants

Trace organic contaminants occur throughout the Greater North Sea area. Some are persistent and recovery times for the environment can be very long. Some reductions in concentration have been observed, but an increasing number of synthetic compounds are detected, for which the ecological effects are largely unknown.

Recommendations call for stronger efforts in the implementation of the OSPAR Strategy on Hazardous Substances[1], and the policies agreed within the frameworks of, for example, the North Sea Conferences, the European Union and the International Maritime Organization.

Nutrients

The anthropogenic inputs of nutrients may cause eutrophication effects, for example increased phytoplankton blooms and oxygen depletion. Heaviest impacts are recognised in estuaries and fjords, the Wadden Sea, the German Bight, Kattegat and eastern Skagerrak. Since 1985, there has been a significant reduction in the total input of phosphorus and, although direct inputs of nutrients have reduced, there was no discernible reduction in the overall nitrogen inputs.

The main recommendations are to pursue vigorously implementation of the OSPAR Strategy to Combat Eutrophication, and where applicable the EC urban wastewater treatment and nitrates directives, and to focus research efforts on links between nutrient enrichment and ecosystem responses.

Second priority class

Oil and PAHs

Reliable estimates on inputs of oil from rivers and land run-off are lacking. Significant reductions are noted for refineries and the offshore oil and gas industry, although for the latter, inputs from produced water have increased progressively in recent years. Polycyclic aromatic hydrocarbons (PAHs) are widespread in the North Sea, but inputs are unknown. Reductions of PAH inputs are expected by virtue of the reduction of inputs of oil.

Recommendations include establishing better estimates of oil and PAH inputs from all land-based sources and of PAH concentrations and effects in the marine environment, fulfilling the objectives of the OSPAR Strategy for offshore oil and gas activities, and strengthening existing measures to ensure continuation of the present decline of illegal discharges of oil from ships.

Heavy metals

Policy measures have been successful in reducing discharges and emissions of cadmium, mercury, lead and copper resulting in reductions of concentrations in sediments, water and biota. However, there is still evidence of local effects close to known sources. Further improvements will be achieved with the fulfilment of the OSPAR Strategy with regard to Hazardous Substances.

Other hazardous substances from sea-based sources (other than oil, PAHs and antifouling substances)

Inputs of hazardous substances occur from the offshore oil and gas industry particularly via produced water. Currently available information is too limited to make an assessment of their impacts. Inputs from shipping consist of elemental phosphorus (found on beaches), pesticides and lipophilic substances originating from the cleaning of tanks, burning fuel, discharges of wastes and loss of cargo.

Recommendations call for more information on inputs, field concentrations, chemical fate and biological effects of the hazardous chemicals concerned. Effective implementation of the OSPAR Strategy for offshore oil and gas activities and various international agreements on shipping should be pursued, with co-operation on control, enforcement and sanctions further strengthened.

Biological impacts

The introduction of non-indigenous species by shipping and mariculture as well as microbiological pollution from land may affect the health of organisms (including man) and the structure of ecosystems.

It is recommended that the presence and further dispersal of non-indigenous species should be recorded, as well as the presence of algal toxins and pathogens, as required for the EU Shellfish Hygiene Directive.

Limitations in knowledge

Limited knowledge in the following subject areas was identified as particularly important:

- The possible impacts of climate change;
- Organic hazardous substances. There is a general lack of data in this area;
- Chemicals from some sectors, for example the offshore industry, shipping and agriculture. Information on inputs, environmental concentrations and biological effects was not readily available;
- Chronic and combined effects of hazardous substances on organisms, and effect concentrations and ecological impacts of substances affecting the hormone system;
- Reliable quantitative information on sources and inputs of nutrients and the relationship with eutrophication, including the role of seasonal variations;
- Trend monitoring. At present, this is unsatisfactory in the OSPAR area;
- Budgets and fluxes for substances, both within the North Sea area and between OSPAR regions. This could be addressed with better harmonised monitoring efforts;
- The lack of Background/Reference Concentrations and Ecotoxicological Assessment Criteria for several hazardous substances;
- Modelling of multi-species interactions in fisheries. Improved data for this purpose are also needed;
- The longer term impacts of fisheries, especially with regard to demersal gears and the seasonal and spatial variability in discards;
- Comparable data on economic aspects of the use of the North Sea;
- Assessment indicators regarding tourism;
- Ecological Quality Objectives to contribute to the protection and conservation of the ecosystems and biological diversity of the maritime area.

Recommendations

The quality status report concludes with the following general recommendations:

- To ensure continued improvement of the quality of the North Sea, adequate resources should be made available to implement the OSPAR Strategies;

[1] The objective of the OSPAR Strategy on Hazardous Substances is to prevent pollution of the maritime area by continuously reducing discharges, emissions and losses of hazardous substances, with the ultimate aim of achieving concentrations in the marine environment near background values for naturally occurring substances and close to zero for man made synthetic substances.

- Future assessments of the quality status of the North Sea could benefit from improved co-operation with other European and global fora;
- Steps should be taken to close the gaps in knowledge highlighted in this report, in particular regarding the occurrence and effects of hazardous substances in the marine environment;
- Further development of tools for the assessment of substances and effects of concern should be pursued, where possible integrating biological effects and chemical monitoring. More efficient data gathering is crucial, for example by one-off surveys by a lead laboratory;
- The impact of those human pressures thought likely to increase, or unlikely to diminish, should be reviewed in the short term and action taken accordingly;
- The implications for the North Sea environment of possible changes associated with global warming should be evaluated;
- The ecosystem approach needs further development and application to achieve effective protection and conservation of the ecosystems and biological diversity of the North Sea.

chapter 1

Introduction

1.1 Scope of the QSR

Assessments of the quality of the marine and coastal environment form a basis for measures for its protection. They provide an opportunity to gather together and assess the results of scientific research and monitoring as well as information on the many human activities that can, directly or indirectly, change or damage the natural attributes of the marine environment. In combination, this information can be used to evaluate the causes and implications of change, and to identify impacts that require early attention by policy-makers and environmental managers. Assessments are also used to review the effectiveness of existing measures to prevent degradation of the marine environment, to protect species and communities and, when practicable, to restore previously damaged marine habitats and ecosystems.

The value of environmental assessments depends to a large extent on the availability of reliable and up-to-date information. Thus it is essential that monitoring and other systems of recording marine environmental information are both ongoing and designed to yield high-quality data amenable to interpretation. In this context, assessments provide a means of reviewing the performance of monitoring programmes and of identifying important gaps in knowledge.

This regional Quality Status Report (QSR) presents an assessment of environmental conditions and of their development in that part of the maritime area of the OSPAR Convention which, for assessment purposes, is known as the Greater North Sea or Region II *(Figure 1.1)*. This is the area defined for the purposes of the North Sea Conferences, but extended to cover the Kattegat. The Greater North Sea is regarded as being bound by the coastlines of England, Scotland, Norway, Sweden, Denmark, Germany, The Netherlands, Belgium, and France, and by imaginary lines delimiting the western approaches to the Channel (5° W), the northern Atlantic between Scotland and Norway (62° N, 5° W), and the Baltic in the Danish Straits.

Together with similar quality status reports for the other four regions (see Foreword), this report forms the basis of a holistic and integrated summary of the quality status of the entire OSPAR maritime area.

1.2 The assessment processes

This assessment is based upon the most recent information available from national and international sources, including OSPAR committees and specialist working groups, the International Council for the Exploration of the Sea (ICES), published reports and the scientific literature. Although most of the information relates to the 1990s, some topics assessed required the use of earlier data, either because the recent record is sparse or because trend analysis involves consideration of historical data. While every effort has been made to ensure the comparability of data from different times and locations, methodologies may differ considerably and some comparisons will, inevitably, be tenuous. Where such uncertainties have been identified, they are indicated in the text.

The most recent previous report on the quality status of the North Sea, covering thirteen subregions, was prepared by the North Sea Task Force under the auspices of the Oslo and Paris Commissions, and ICES, and was published in 1993 (1993 QSR). The present report mainly summarises the information which has become available since that time, but some data from the 1993 QSR has been used as background material.

Each of the Chapters of this report were drafted by an individual member country of the Regional Task Team following guidelines agreed by OSPAR. For the ‘Overall Assessment’ in Chapter 6, a structured expert judgement method was used to assist in the assessment process and to attempt to prioritise human pressures according to their impact in this region. A description of this process is given in Chapter 6.

Figure 1.1 **Region II and the other regions of the OSPAR maritime area.**

1.3 Guidance to the reader

Chapter two gives a concise description of the status and development regarding physical geography, hydrography and climate of the region, as these have an important bearing on the types and distributions of marine habitats and communities, as well as on their sensitivity to environmental change. Substantial information was provided in the 1993 QSR, and much of this is still relevant. However, it has been updated with new information on bottom topography, river systems, estuaries and coastal characteristics. Use has been made of the latest developments in mathematical modelling.

Chapter three examines human activities that directly or indirectly impinge on marine areas, their amenities and resources, and also identifies localities most involved, assessing any apparent trends. The North Sea is surrounded by densely populated, highly industrialised countries and it is one of the busiest sea areas of the world. Up to date information is provided on all of these human activities, including the various Agreements and Conventions covering them.

The next two chapters summarise information on chemical and biological features of the various coastal and offshore ecosystems, focusing in particular on the causes and implications of the changes that are occurring.

Chapter four contains the latest available information on developments in riverine, sea-based and atmospheric inputs of contaminants, such as heavy metals, persistent organic pollutants, oil, radionuclides and nutrients. For the various groups of substances, geographic and temporal comparisons are made of concentrations in water, sediment and biota. Whenever possible, environmental risks are assessed.

Chapter five is essentially in two parts. The first part contains a short description of some of the most important aspects of the structure and function of the North Sea ecosystem, including food webs and biological production processes. Since the 1993 QSR described the North Sea ecosystem in considerable detail, only general information on key functional organisms and their status is given in this report. The second part of this chapter is linked to chapters three and four through a description and discussion of the nature and extent of the various impacts affecting the biota of the region.

Finally, Chapter six draws on the preceding chapters to identify throughout the region the major causes of any environmental degradation, where improvements have been achieved, and recommendations for the managerial and scientific actions needed to address any impacts.

Where scientific and other terms have been used, their meanings are both defined in the text and included in a glossary of terms. There is also a list of the English and (scientific) species names of the organisms mentioned in the text.

chapter 2

Geography, hydrography and climate

GEOGRAPHY

2.1 Introduction

This chapter defines the principal geographical characteristics of the Greater North Sea. Its aim is to set the scene for the more detailed descriptions of the physical, chemical, and biological characteristics of the area and the impact man's activities have had, and are having, upon them. For various reasons, certain areas (here called 'focus areas') have been given special attention.

2.2 Definition of the region

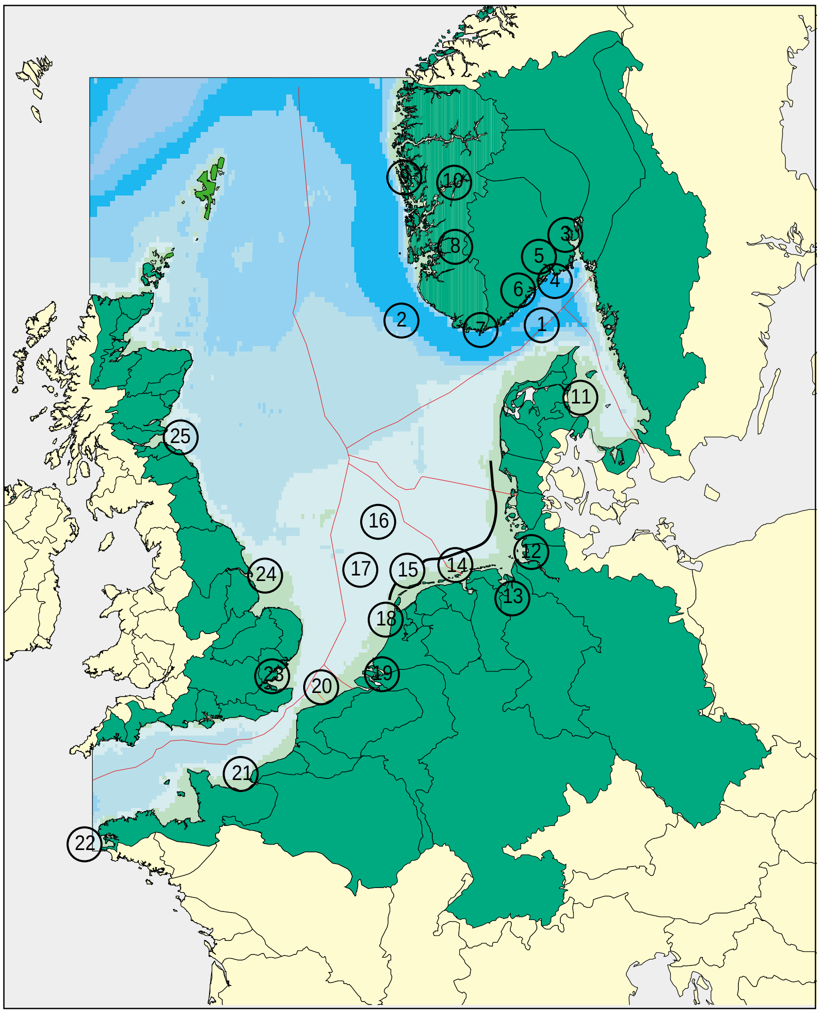
The Greater North Sea, as defined in chapter one, is situated on the continental shelf of north-west Europe. It opens into the Atlantic Ocean to the north and, via the Channel to the south-west, and into the Baltic Sea to the east, and is divided into a number of loosely defined areas. The open North Sea is often divided into the relatively shallow southern North Sea (including e.g. the Southern Bight and the German Bight), the central North Sea, the northern North Sea, the Norwegian Trench and the Skagerrak. The shallow Kattegat is seen as a transition zone between the Baltic and the North Sea. The Greater North Sea (including its estuaries and fjords) has a surface area of about 750 000 km^2 and a volume of about 94 000 km^3.

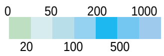
2.3 Bottom topography

The bottom topography is important in relation to its effect on water circulation and vertical mixing. Flows tend to be concentrated in areas where slopes are steepest, with the current flowing along the contours. The depth of the North Sea *(Figure 2.1)* increases towards the Atlantic Ocean to about 200 m at the edge of the continental shelf. The Norwegian Trench, which has a sill depth (saddle point) of 270 m off the west coast of Norway and a maximum depth of 700 m in the Skagerrak, plays a major role in steering large inflows of Atlantic water into the North Sea.

The Channel is relatively shallow, and from a depth of about 30 m in the Strait of Dover deepens gradually to about 100 m in the west. Seabed topography shows evidence of river valley systems that were carved into the seabed during glacial periods when the sea level was lower.

Figure 2.1 **Bottom topography and catchment areas of the Greater North Sea. Location of focus areas.**





1. Skagerrak
2. Norwegian Trench
3. Inner Oslofjord
4. Sandefjord
5. Drammensfjord
6. Grenlandsfjord
7. Kristiansandsfjord
8. Saudafjord
9. Bergensfjord
10. Sørfjord/Hardangerfjord
11. Kattegat
12. Elbe
13. Weser
14. Jade
15. Wadden Sea
16. Oyster Ground
17. Frisian Front
18. Dutch coastal zone
19. Scheldt estuary
20. Flemish Banks
21. Seine estuary
22. Rade de Brest
23. Thames estuary
24. Humber estuary
25. Firth of Forth

In the area between The Netherlands and Great Britain, extending northwards from the Channel to the Frisian Front (45 m), average depths are between 20 and 30 m. On the north-west side of the Dutch part of the continental shelf lies the shallow area of the Dogger Bank where depths can be less than 20 m. This bank has a significant impact on the circulation in the southern North Sea and is an important fishing area.

Many estuaries and fjords flow into the North Sea *(Figure 2.1)*. Fjords are often considered as a special type of estuary, some being quite deep with a shallower sill at the mouth.

2.4 Geology and sediments

The North Sea shelf area is an ancient continental drift depression with a general north-south axis. This depression is overlain by sedimentary deposits several kilometres thick originating from the surrounding land masses, and some of their strata contain large amounts of liquid and gaseous hydrocarbons, which are intensively exploited.

During the glacial era, multiple invasions of Scandinavian and Scottish mountain glaciers spread over the North Sea causing large sea level changes and supplies of additional sediment into the North Sea basin. It also shaped the general style of the present underwater topography, for instance, elevations such as the Dogger-Fisher Bank and depressions like the Oyster Ground, the submerged part of the Elbe valley, Devil's Hole, Fladen Ground and the Norwegian Trench.

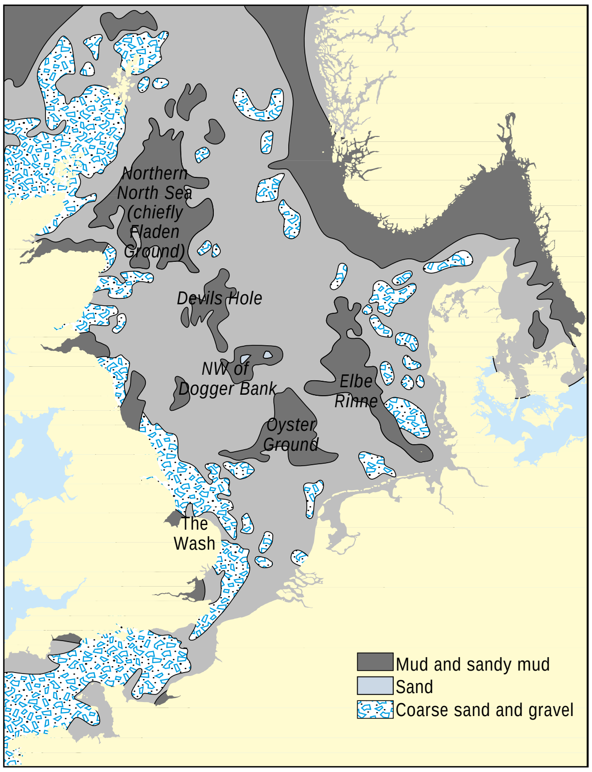
Sea levels rose from the end of the last glaciation until about 6 000 years ago, but since that time there have been only minor variations. The resulting hydrographic circulation, as well as the wave and tidal regime, created the sediment dynamics and the sediment distribution pattern seen today. Mainly sand and gravel deposits occur in the shallower areas and fine-grained muddy sediments accumulate in many of the depressions *(Figure 2.2)*.

Tidal flats like the Wadden Sea and the Wash receive their sediments directly or indirectly from rivers and from adjacent North Sea areas. The suspended particulate matter settles to form either sandy or muddy sediments according to its composition and the predominant local hydrodynamic conditions.

2.5 Description of the coastal margin

The coastlines of the Greater North Sea display a large variety of landscapes arising from differences in geology and vertical tectonic movements. The disappearance of the weight of ice after glaciation has led to the vertical uplift of northern coastlines. The coastlines of Norway and northern Scotland are mountainous with many rocky islands, and are often dissected by deep fjords. Most of the Swedish and Norwegian mainland is sheltered from the open ocean by a 'continuous' archipelago.

Figure 2.2 **Sediment types. Named locations are areas of mud and sandy mud. Source: after Eisma (1981).**



The coasts of northern England and Scotland feature cliffs of various sizes, some with pebble beaches, but also intersected by river valleys. The east coast of England is characterised by estuaries such as those of the Humber and Thames, and by further expanses of sand and mud flats in areas such as the Wash. Along the Channel the coastline of south-east England is dominated by low cliffs and flooded river valleys. From east to west along the French coast of the Channel are maritime plains and estuaries, cliffs, and the rocky shore of Brittany.

From the Strait of Dover to the Danish west coast, sandy beaches and dunes prevail, with numerous estuaries (e.g. of the Scheldt, Rhine, Meuse, Weser and Elbe) and the tidal inlets and islands of the Wadden Sea. This area displays signs of slow subsidence over a geological time scale. In Denmark large lagoon-like areas exist behind long sandy beaches.

The natural coastline of the Southern Bight has been changed considerably by human intervention such as the development of towns and harbours, land reclamation projects, and coastal protection structures as well as important ports and industries at river mouths and estuaries.

2.6 Estuaries, fjords and wetlands

Estuarine and wetland habitats occur at the transition between coast and the open sea. These shallow tidal areas have a naturally high level of productivity that, in some cases, is enhanced by an anthropogenic supply of nutrients carried by rivers. The richness of the benthic life supports high numbers of resident, overwintering, and migratory waterfowl. These areas are also important as nurseries for juvenile fish, and the intertidal shoals are attractive resting sites for seals.

However, these same habitats can suffer from the accumulation of contaminants due to net sedimentation of particles from upstream sources and the sea (see Chapter 4). Ecologically important estuaries and wetlands are found in the Limfjord, the Wadden Sea, the Wash, the Dutch Delta coast, and the Channel estuaries along the coasts of France and England.

The archipelago and the fjords along the Swedish coast in the Skagerrak and northern Kattegat are very sensitive to eutrophication and other effects of human activities. Water exchange with the open sea is restricted in several places by narrow straits and shallow sills in combination with weak tides. This region is also subject to considerable environmental pressure due to increasing recreational use. In typical Norwegian fjords with significant water exchange to the open sea, increased oxygen consumption in the 1980s, which remained high in the 1990s, seems to a large extent to be the result of increased eutrophication of the Skagerrak. (Aure *et al*., 1996).

2.7 Catchment area

River systems that discharge into the Greater North Sea *(Figure 2.1)* have a total catchment area of about 850 000 km^2, and the annual input of fresh water from these river systems is of the order of 300 km^3 *(Table 2.1)*. The annual run-off, carrying anthropogenic contaminants to the sea from land based sources, is however highly variable, and this is important for the transport of contaminants. Melt water from Norway and Sweden constitutes about one third of the total run-off. The rivers Elbe, Weser, Rhine, Meuse, Scheldt, Seine, Thames and Humber are the most important in the catchment area.

However, the dominating source of fresh water to the North Sea is the rivers discharging into the Baltic Sea. Its catchment area is about 1 650 000 km^2. The net fresh water supply to the Baltic is about 470 km^3/yr. This water leaves the Baltic with a salinity of about 10 and has a profound influence on the hydrography and water movements in the eastern parts of the North Sea. The inflow from the Baltic is an additional source of contaminants and nutrients to the North Sea (HELCOM, 1996).

2.8 Focus Areas

Many areas in the Greater North Sea region may consist of a typical and valuable habitat for marine life, be under (anthropogenic) stress or be of strategic or economic importance, and as such deserve special attention. A number of such ‘focus areas’ have been defined in this report for the above mentioned reasons, or because scientific research has resulted in a relatively large amount of information and, hence, understanding of the functioning of such an area. Selected focus areas which serve as examples of a variety of typical areas in the Greater North Sea, are described in *Table 2.2* and shown in *Figure 2.1*.

Table 2.1 Mean annual river run-off to the North Sea. Source: adapted from NSTF (1993).

Area	Run-off (km^3/yr)	Catchment area (km^2)
Norwegian North Sea coast	58 – 70	45 500
Skagerrak and Kattegat coasts	58 – 70	102 200
Danish and German coasts (including their Wadden Sea coasts)	32	219 900
Dutch and Belgian coasts (including Dutch Wadden Sea, Rhine, Meuse and Scheldt)	91 – 97	221 400
English and French Channel coasts (including Seine)	9 – 37	137 000
English east coast (including Tyne, Tees, Humber, Thames)	32	74 500
Scottish coast (including Forth)	16	41 000
Total North Sea region	296 – 354	841 500
Baltic Sea region	470	1 650 000

Table 2.2 Focus areas with their characteristics (see also Figure 2.1).

Focus areas	Description of the geographic and hydrographic characteristics
Skagerrak-Norwegian Trench	The deep Norwegian Trench in the northeastern North Sea ends up in the even deeper Skagerrak. Due to this topography large amounts of Atlantic water flow into the area. This, together with the general anti-clockwise circulation of the North Sea, causes most of the water in the North Sea to pass through this area. Moreover all the water from the Baltic Sea passes through it. It also receives major riverine inputs from Norway and Sweden. Increased oxygen consumption in the water and large amounts of contaminants in the sediments are issues of concern. The residence time of the Skagerrak surface water is typically about a month, while the deepest water (500 – 700 m) may be stationary for several years.
Norwegian fjords: inner Oslofjord, Sandefjordsfjord, Drammensfjord, Grenlandfjord, Kristiansandsfjord, Saudafjord, Bergenfjord, Sørfjorden/ Hardanger fjord	These fjords have in common that most of them have a significant fresh water supply in their inner part where also industry and cities are located. Their fine sediments are significantly contaminated. They have a typical estuarine circulation in the upper layers. Some of the fjords (or parts of the fjords) have a relatively shallow sill. In the often deep basins landward of the sill the water is generally stagnant for one or several years, depending mainly on the sill topography, the strength of vertical mixing, and the hydrography outside the fjords. The residence time of the surface water depends mainly on the length of the fjord and the freshwater discharge.
Kattegat	The relatively shallow Kattegat has an estuarine-like circulation. The almost fresh water from the Baltic Sea overlays the saltier water from the Skagerrak, coming from the southern North Sea. The strong salinity stratification hinders vertical wind mixing of the deeper water where frequently oxygen depletion occurs. The residence time of the surface water is just a few weeks, and of the bottom water a few months.
Elbe and Weser estuaries, Jade Bay	The Elbe and the Weser have river mouths which discharge huge volumes of (contaminated) fresh water into the southeastern corner of the North Sea and into the Wadden Sea. The Jade Bay is a Wadden Sea-like tidal inshore basin connected to the open sea by a narrow channel. All three have important shipping lanes and are thus subject to intensive dredging and deepening. The Elbe and the Weser have a strong and stable vertical salinity stratification although tidal and wave activity can be very strong. In the Jade Bay small fresh water input and very strong tidal currents suppress the development of stratification.
Wadden Sea (including Ems-Dollard)	Extends along the North Sea coasts of The Netherlands, Germany and Denmark, from Den Helder to the Skallingen peninsula near Esbjerg. It is a highly dynamic area of great ecological significance. With 500 km it is the largest unbroken stretch of mudflats in the world. According to the delimitation of the trilateral cooperation, the Wadden Sea covers about 13 000 km^2, including some 1 000 km^2 islands, 350 km^2 salt marshes, 8 000 km^2 tidal areas (sub-tidal and inter-tidal flats) and some 3 000 km^2 of offshore area. The border to the North Sea is approximately the 10 m isobath. Most parts of the Wadden Sea are sheltered by barrier islands and contain smaller or wider area of intertidal flats. The Wadden Sea hydrology is mainly determined by the daily tides. With each high tide an average of 15 km^3 of North Sea waters enters the Wadden Sea, thereby doubling the volume from 15 km^3 to about 30 km^3. With the North Sea water also nutrients and suspended particular matter reach the Wadden Sea, through the tidal inlets. In the North of Holland there is also a structural loss of sand to the Wadden Sea. There is a structural loss of sand from the offshore area to the tidal area causing erosion of the foreshore and beaches of several islands.
Oyster Ground, Frisian Front	In contrast with the shallower parts of the North Sea, which are well-mixed from surface to bottom throughout the year, this part of the North Sea (45 m) becomes statically stratified in Spring, after a period of sufficient isolation and the stratification generally lasts through the Summer. In this area the water depth exceeds the sum of the depth of a wind mixed near-surface layer (10 – 15 m) and that of a tidally mixed near-bottom layer (10 – 30 m).
Dutch Coastal Zone	The coastal zone along the entire western and northern half of the Netherlands can be considered as one of the most densely populated areas in Europe. The coastal zone is protected from the sea by natural sand-dunes (254 km) and sea dikes (34 km), beach flats (38 km) and 27 km of boulevard, beach walls and the like. The width of the coastal dunes varies between less than 200 m and more than 6 km.

(table continues over)

Dutch Coastal Zone (cont.)	The upper shore face is a multi-barred system generated by normal wave action, while its lower part is dominated by storm sedimentation, down to the depth of about 16 m. At greater depths tidal currents play a significant role along with storm waves, keeping fine-grained sediment in suspension. Below the shore face in a water depth of 14 – 23 m a broad field of sand ridges, and in water depths greater than 20 m a large field of sand waves (height 2 – 10 m) is present. Mixing of river water from Meuse and Rhine occurs only gradually and over long distances in a northward direction.
Scheldt estuary	A well-mixed estuary with a yearly average upstream freshwater flow rate of 107 m^3/sec. The total drainage area is 20 300 km^2. The estuary consists of an alternation of transition zones: deep ebb and flood channels, large shallow water zones, tidal flats and dry shoals.
Flemish Banks	A highly dynamic system of shallow, elongated sandbanks off the Belgian coast. The sediments consist of well-sorted fine to medium sands.
Seine Estuary	It is a well-mixed estuary with a yearly average freshwater flow rate of 380 m^2/sec. The total drainage area is 75 000 km^2. The estuary is subject to large tidal differences (7 m). The principal physical and sedimentological phenomena are governed by this tidal regime.
Rade de Brest	This bay covers only 180 km^2, but the catchment area covers 2800 km^2.
UK estuaries	UK estuaries vary considerably in their characteristics. This reflects the wide differences in the topography and geology of the catchment areas, in the extent of anthropogenic influence, and in the geographical features of the coastal areas. Generally freshwater flows are at the lower end of the range typical for estuaries feeding into the Greater North Sea. Conditions in UK estuaries are strongly influenced by large tidal ranges and water movements.
Oil and gas fields	The oil and gas fields are located over most of the North Sea (cf. Section 3.10). Some substances discharged by the offshore oil and gas industry are typically found in the sediments of the Skagerrak and the Norwegian Trench, where these were earlier believed to deposit and accumulate very close to the installations. During severe storms significant resuspension may occur in water depths even down to 100 m due to wave action.

HYDROGRAPHY

2.9 Introduction

This chapter reviews the physical processes that have a direct influence on the ecology of the Greater North Sea. Knowledge of these processes is required in order to link inputs of dissolved and particulate matter to their concentrations and effects upon the ecosystem.

It also serves to distinguish between natural variability and man's impact, and to predict the possible effects of climatic and other long-term changes/variability. It should be stressed that the functioning of the North Sea is highly dependent upon the variable water exchange with surrounding ocean areas. It is also worth noting that some important phenomena such as the resuspension of sediments and transport of matter from the southern North Sea towards the Skagerrak are highly driven by 'events', often related to extreme weather conditions.

2.10 Water mass characterisation

The water of the shallow North Sea consists of a varying mixture of North Atlantic water and freshwater run-off. The salinity and temperature characteristics of different areas are strongly influenced by heat exchange with the atmosphere and local freshwater supply. The deeper waters of the North Sea consist of relatively pure water of Atlantic origin, but they too are partly influenced by surface heat exchange (especially winter cooling) and, in certain areas, slightly modified through mixing with less saline surface water.

Several water mass classifications exist for the North Sea, based on temperature and salinity distributions or on residual current patterns or stratification. The main water masses and their temperature and salinity ranges are summarised in *Table 2.3* and *Figures 2.3* and *2.4*.

The circulation and distribution of these water masses is of the utmost importance in supporting biological productivity, transport and concentration of living (e.g. larvae) and non-living matter in the region.

2.10.1 Physical parameters: salinity/temperature/light transmission

In coastal waters beyond estuaries and fjords, typical salinity ranges are 32 to 34.5, except in the Kattegat and parts of Skagerrak where the influence from the Baltic results in salinities in the ranges 10 – 25 and 25 – 34, respectively. In the open waters and especially in western

Figure 2.3 **Schematic diagram of general circulation in the North Sea. Source: after Turrell *et al*. (1992).**

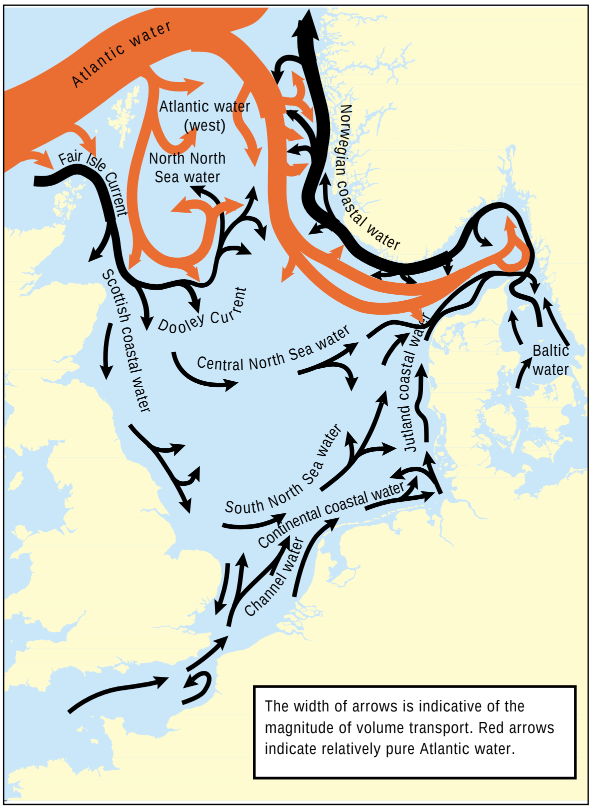


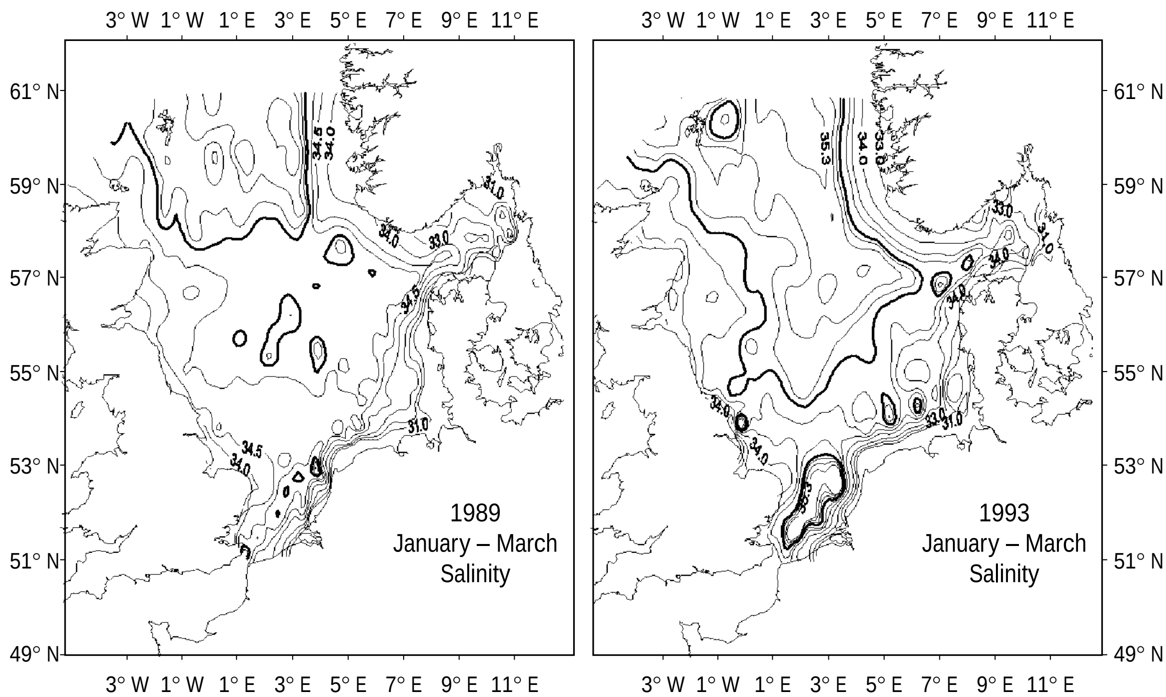
Table 2.3 Typical values for salinity and temperature of water masses in the North Sea. Source: adapted from NSTF (1993).

Water mass	Salinity	Temperature (°C)
Atlantic water	> 35	7 – 15
Atlantic water (deep)	> 35	5.5 – 7.5
Channel water	> 35	6 – 18
Baltic water	8.5 – 10	0 – 20
Northern North Sea water	34.9 – 35.3	6 – 16
Central North Sea water	34.75 – 35.0	5 – 10
Southern North Sea water	34 – 34.75	4 – 14
Scottish coastal water	33 – 34.5	5 – 15
Continental coastal water	31 – 34	0 – 20
Norwegian coastal water	32 – 34.5	3 – 18
Skagerrak water	32 – 35	3 – 17
Skagerrak coastal water	25 – 32	0 – 20
Kattegat surface water	15 – 25	0 – 20
Kattegat deep water	32 – 35	4 – 15

parts of the North Sea, seasonal changes in sea surface salinity (around 35) are comparatively small.

Large annual changes can be seen in the regional distribution of sea surface salinity (SSS) *(Figure 2.4)*, and long term salinity records of the North Sea *(Figure 2.5b)* also show significant variability. Relatively high salinities occurred in the 1920s, at the end of the 1960s, and from 1989-95, whereas salinities were very

Figure 2.4 **Surface salinity distribution for the winters of 1989 and 1993 as an example of interannual variability. Source of data: ICES.**



low in the late 1970s and most of the 1980s. The high salinities are primarily caused by a combination of reduced freshwater input and vertical mixing, as well as increased influx of Atlantic water (see also section ‘Climate’).

North Sea sea surface temperatures (SST) show a strong yearly cycle, with amplitudes ranging from 8 °C in the Wadden Sea to less than 2 °C at the northern entrances *(Figures 2.5a, 2.6a)*. The increasing amplitude towards the south-east is related to the greater proportion of low salinity coastal water and the reduced depth. The long-term annual mean *(Figure 2.6b)* shows small differences in the North Sea area with a mean value of about 9.5 °C. The shape of the 11 °C isotherm indicates the inflow of warmer water from the English Channel into the North Sea. The lowest temperatures *(Figure 2.6c)* in the northern Atlantic inflow area have decreased in the 25 years period (from 1969 to 1993) by about 1 °C. The highest temperatures *(Figure 2.6d)* have increased in that area by about 1 °C, and in the northern North Sea by about 2 °C (Becker and Schulz, 1999). This increase has also been observed in the continental coastal zone. The ‘Cold Belt’ connected with the tidal mixing front off the East Frisian Islands – shown by the course of the 20 °C isotherm – is clearly visible. In general, the North Sea SST seems to be rather stable (see section ‘Climate’). The long-term variability of the SST is closely correlated with the strength of the atmospheric circulation of the North Atlantic, the North Atlantic Oscillation (NAO).

Light transmission through the water column is mainly limited by the presence of suspended matter and plankton. The spatial and temporal variability in concentrations of plankton and suspended matter results in high variability in light transmission. *Figure 2.7* illustrates the high turbidity associated with river outflow, high plankton concentrations and/or resuspension of bottom sediments. Such features are frequently observed in satellite images of ocean colour.

Figure 2.5 **Monthly mean sea surface (a) temperature and (b) salinity for the period 1873–1994 measured at Helgoland-Roads. Source of data: Becker *et al*. (1997).**

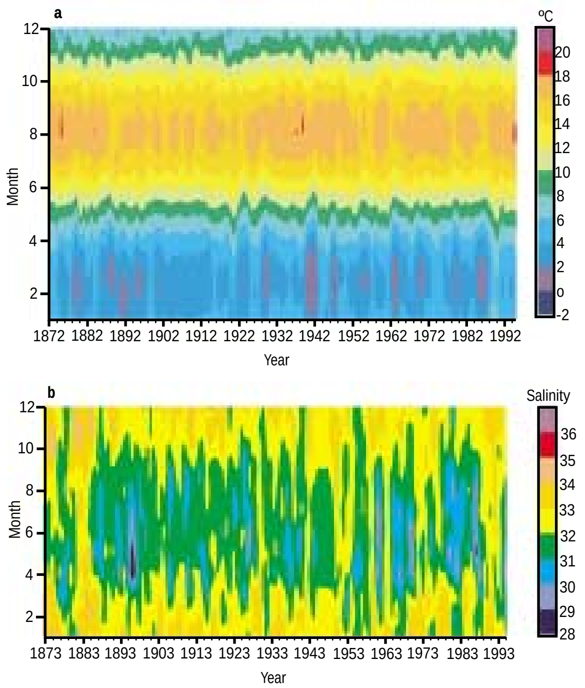
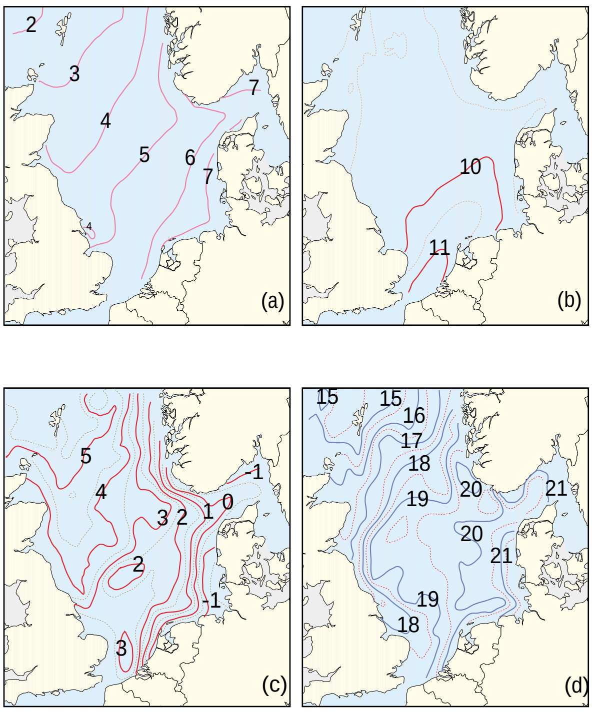


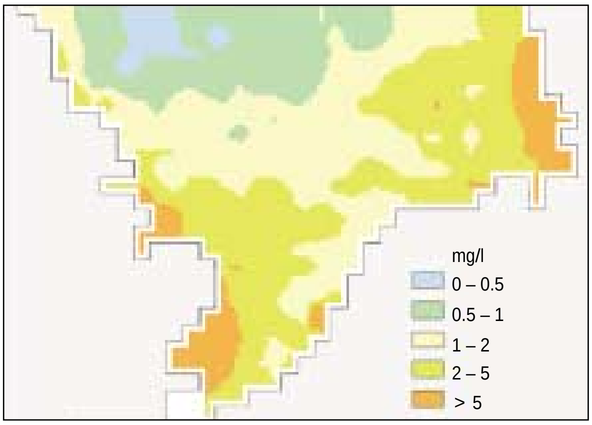
Figure 2.6 **The North Sea sea-surface temperature distribution in °C (1969–93): (a) amplitude of the yearly cycle; (b) mean; (c) minima; (d) maxima. Source of data: Becker and Schulz (2000).**



2.10.2 Stratification

In winter months, most areas of the North Sea outside the Norwegian Trench, the Skagerrak and the Kattegat are vertically well mixed. In late spring, as solar heat input increases, a thermocline (a pronounced vertical temperature gradient) is established over large areas of the North Sea. The thermocline separates a heated and less dense surface layer from the rest of the water column where the winter temperature remains. The strength of the

Figure 2.7 **Distribution of depth and time averaged concentration of suspended particulate matter in the southern North Sea. Source of data: projects NERC-NSP (UK, 1988–9), TUVAS (Germany, 1989–92) and KUSTOS (Germany, 1994–6).**



thermocline depends on the heat input and the turbulence generated by the tides and the wind. This is demonstrated in two temperature sections taken during summer, one 350 km long north-westward across the Dogger Bank from the island of Terschelling (Dutch Wadden Sea) *(Figure 2.8)* and one between Norway and Scotland, along 57° 17' N, in the northern North Sea, the latter also showing the salinity and density distribution *(Figure 2.9)*. *Figure 2.8* demonstrates that the water is vertically well mixed along the continental coast, and also to a certain extent over the Dogger Bank.

The depth of the thermocline increases from May to September and differs regionally, in August/September being typically 50 m in the northern North Sea and 20 m in the western Channel. In autumn, the increasing number and severity of storms and seasonal cooling at the surface destroy the thermocline and mix the surface

Figure 2.8 **Vertical temperature section in °C north-northwest from Terschelling (The Netherlands) taken on 26 July 1989 and showing stratification.**

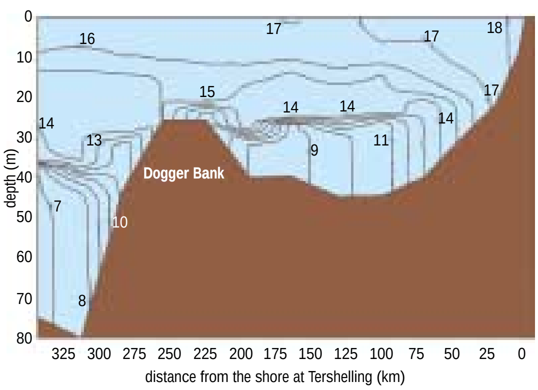
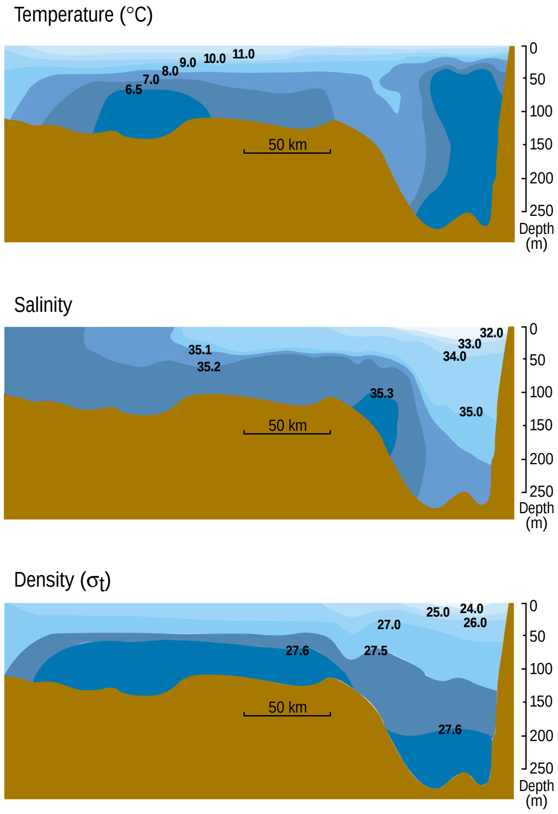


Figure 2.9 **Mean summer vertical temperature, salinity and density sections between Norway and Scotland along 57° 17' N.**

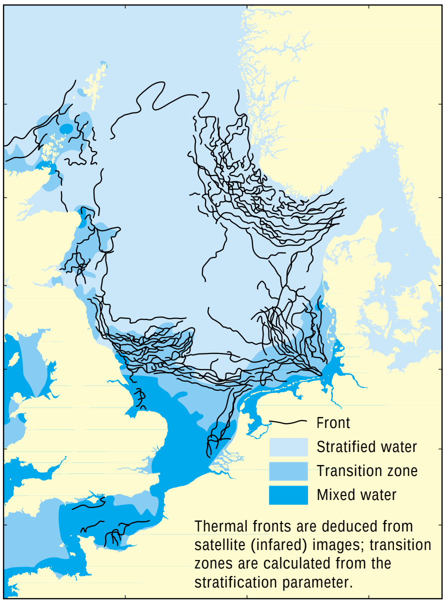


and bottom layers. The shallow parts of the southern North Sea and the Channel remain well mixed throughout the year owing to strong tidal action. The Kattegat, Skagerrak, and Norwegian Trench region of the North Sea are strongly influenced by fresh water input, and, due to the low salinity in their upper layer, have a stable stratification all year round. The deep water in these areas is not mixed with the surface water. It is mainly renewed by subduction of saltier water originating from other parts of the North Sea. The salinity stratification in these regions has large implications for their primary productivity. The spring bloom starts earlier here than in other areas where stratification due to the heating must precede the bloom. To some extent, the same applies to areas off the mouths of large continental rivers.

2.10.3 Fronts

Fronts or frontal zones mark the boundaries between water masses and are a common feature in the North Sea *(Figure 2.10)*. Fronts are important because they may restrict horizontal dispersion and because there is enhanced biological activity in these regions. They can

Figure 2.10 **Transition zones between mixed and stratified water in the North Sea. Source: Becker (1990).**



also mark areas where surface water is subducted to form deeper water. Three types of front are present in the North Sea: tidal fronts, upwelling fronts and salinity fronts.

Tidal fronts mark the offshore limit of regions where tide induced mixing is sufficient to keep the water column mixed in competition with the heating of the surface layer. These fronts develop in summer in the western and southern parts of the North Sea where tidal currents are sufficiently strong.

Upwelling fronts form along coasts in stratified areas when the wind forces the surface water away from the coast, thus allowing deep water to surface along the coast. The formation of such fronts are common in the Kattegat, Skagerrak and along the Norwegian coast.

Salinity fronts form where low salinity water meets water of a higher salinity. Prominent salinity fronts are the Belt front which separates the outflowing Baltic surface water from the Kattegat surface water, the Skagerrak front separating the Kattegat surface water from the Skagerrak surface water and the front on the offshore side of the Norwegian coastal current *(Figure 2.11)*. Fronts can have currents, meanders and eddies associated with them.

In many near-shore regions of the North Sea, strong tidal currents are oriented parallel to the coast. In areas such as the Rhine/Meuse outflow, for example, river water spreads along the Dutch coastline. This water overlies the denser, more saline sea water, and a pattern of estuarine circulation is established perpendicular to the coast. The concentrations of any contaminants contained in these riverine waters can be significantly higher close to the coast, even at some distance from the estuary concerned. Abrupt changes in topography as well as unusual weather conditions can cause currents to deviate from this longshore alignment.

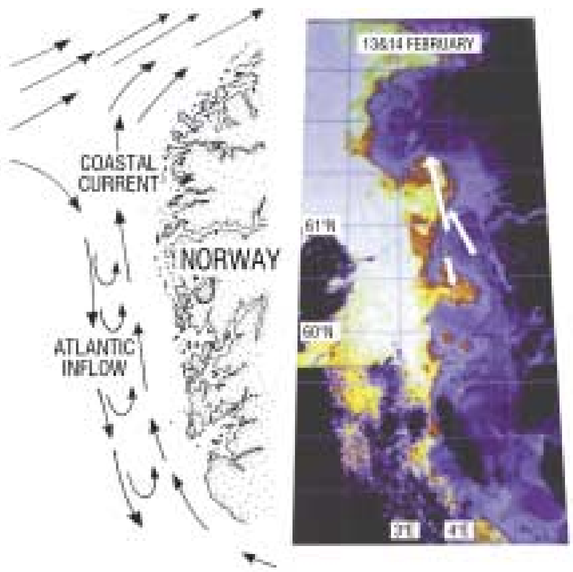
2.11 Circulation and volume transport

2.11.1 Circulation

The mean currents of the North Sea form a cyclonic circulation *(Figure 2.3)*. The bulk of the transport in this circulation is concentrated to the northern part of the North Sea due to major water exchange with the Norwegian Sea. The main inflow occurs along the western slope of the Norwegian Trench. Considerable inflows also take place east of the Shetland Islands and between Shetland and the Orkney Islands. Less than 10% enters through the Channel. All of these inflows are compensated by an outflow mainly along the Norwegian coast.

Westerly winds enhance the cyclonic circulation whereas winds from the east weaken the circulation (Dooley and Furnes, 1981). The circulation can occasionally reverse into an anti cyclonic direction. Observations show that the short-term variations of the horizontal

Figure 2.11 **An example of circulation patterns and fronts in the northern North Sea: NOAA satellite infrared images obtained for February 1986. Source: Johannessen *et al*. (1989).**



Yellow represents Atlantic water (T > 7 °C), dark blue represents coastal water (T < 3 °C). Clouds appear as black areas over the ocean. White arrows represent daily mean current vectors at 25m or 50m from three moorings.

transport in the Norwegian Trench are of the same order of magnitude as its mean value (Furnes and Saelen, 1977). In the rest of the North Sea, however, the wind-forced variations of the horizontal transport are one order of magnitude larger than its mean.

It seems as if most of the water in the different inflows from the north-west are guided eastwards (the Dooley Current) to the Norwegian trench by the topography along the 100 m depth contour. Only a small part flows southward along the coast of Scotland and England.

To demonstrate the variability in current pattern and magnitude, mean winter circulation (January-March) at 10 m depth was modelled for a year with a typically high (1990) and a year with a typically low (1985) inflow of Atlantic Water *(Figure 2.12)*. This clearly demonstrates the much stronger currents all over the North Sea in 1990 compared to 1985. Much of the schematic circulation pattern from *Figure 2.3* is also revealed in the 1990 model results. While significant inflows of Atlantic Water occurred in 1990, both from the north and through the Channel (resulting in the highest salinities ever measured (Heath *et al*., 1991; Ellet and Turrell, 1992)), there was a tendency in 1985 for outflow through the Channel and relatively weak inflows to the north. These drastic differences from year to year (mainly caused by differences in atmospheric forcing) explain some of the large scale differences in the salinities shown in *Figure 2.4*.

A part of the northern inflow in the Norwegian Trench crosses the trench north of the sill (saddle point) off western Norway and returns northward (Furnes *et al*., 1986). However, before it leaves the North Sea, most of the water probably passes through the Skagerrak – with an average cyclonic ‘counter clockwise’ circulation – before leaving along the Norwegian coast. The water in the deepest part of the Skagerrak is renewed by cascades of dense water formed during cold winters over the more shallow parts west of the trench in the northern North Sea (Ljøen and Svansson, 1972).

In recent years, concern about algal blooms as the cause of serious problems for fish farming has led to a special interest in the inflow of the nutrient-rich water from continental rivers to the Skagerrak/Kattegat. Strong inflows occur in pulses, mainly during winters with strong southerly to westerly winds.

The residual flow in the Channel is to a large extent steered by the wind and tide. On average, this flow is from south-west to north-east, feeding a relatively narrow and saline core of Atlantic water through the Strait of Dover. The mean transport eastwards into the North Sea is confirmed by the evidence seen in the dispersion of radionuclides discharged by the Cap de la Hague nuclear reprocessing plant *(Figure 2.13)*.

2.11.2 Bottom water movement

In the tidally well-mixed waters of the western and southern regions of the North Sea, large-scale movements are generally independent of depth

Figure 2.12 **Modelled mean currents during the first quarter (January to March) in 1990 and 1985 obtained with the NORWECOM model.**

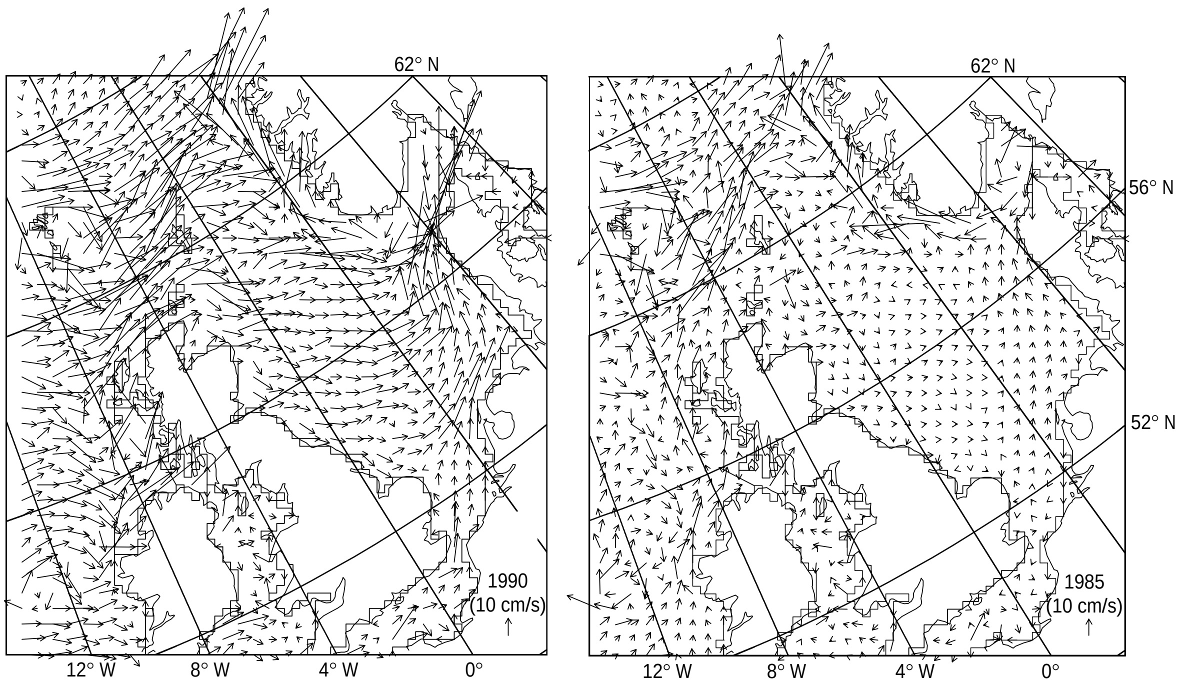
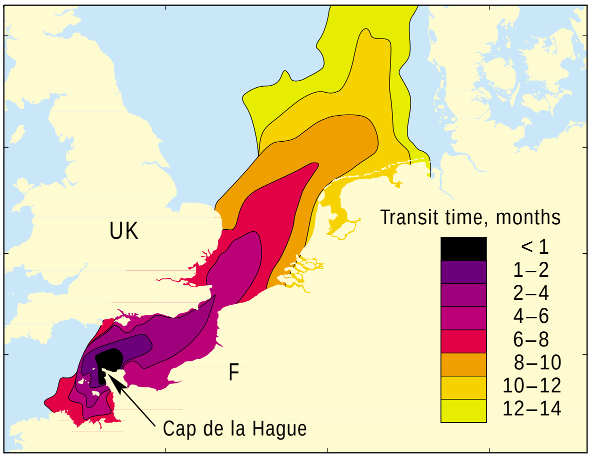


Figure 2.13 **Dispersion of nuclear industry wastes in the Channel and the North Sea. Transit time (derived from radionuclide concentrations) for dissolved chemicals released at Cap de la Hague. Source: Breton *et al*. (1992).**



throughout the year. Elsewhere, the movement of North Sea bottom water at great depths has a very strong seasonal signal, with large areas becoming almost motionless during the summer. These areas are usually marked by depressed oxygen levels (to a minimum of about 65% saturation) and by temperatures similar to those of the preceding winter. Such a situation is typical in large areas of the central and northern North Sea at depths greater than about 70 m; an exception to this is the areas adjacent to bottom slopes where much of the water circulation is trapped. The situation is, however, usually very temporary as convection and mixing processes in autumn cause a rapid renewal of these deep waters. The areas permanently stratified by salinity have a generally slow bottom water exchange. In the Kattegat, the bottom water is renewed in 1 – 4 months, the longest period during summer. This slow renewal, in combination with eutrophication, frequently leads to periods of low oxygen content. The slowest movement of bottom water occurs in central parts of the Skagerrak where depths exceed 700 m. Here, waters are normally replaced at a much slower rate (every 2 – 3 years), but rapid changes can occur when bottom water cascades into the Norwegian Trench in winter (Ljøen, 1981).

2.11.3 Volume transport and water balance

Because water fluxes can rarely be directly measured, water balances for the North Sea are mainly based upon model results. Due to differences between models in assumptions and forcings, different models often give different results. However, intercomparison exercises, such as during the EU NOWESP and NOMADS projects, indicate that a few of the larger models which include the surrounding waters of the North Sea seem to give quite similar results.

A compilation of literature results for residual flow through the Strait of Dover shows a range of 0.09 – 0.15 Sverdrup (1 Sverdrup = 10^6 m^3/s) for flows induced by wind and tide (Boon *et al*., 1997) *(Table 2.4)*. A recent study of transport and long-term residual circulation in the north-west European shelf using hydrodynamic models gave values of 0.01 and 0.06 Sverdrup through the Strait of Dover from 2 different models (Smith *et al*., 1996). In the same study, the range for net residual outflow through the northern North Sea between the Shetland Islands and Norway (~ 61º N) was 0.39 – 0.96 Sverdrup, while the inflow between the Scottish mainland and the Shetland Islands ranged from 0.14 – 1.1 Sverdrup.

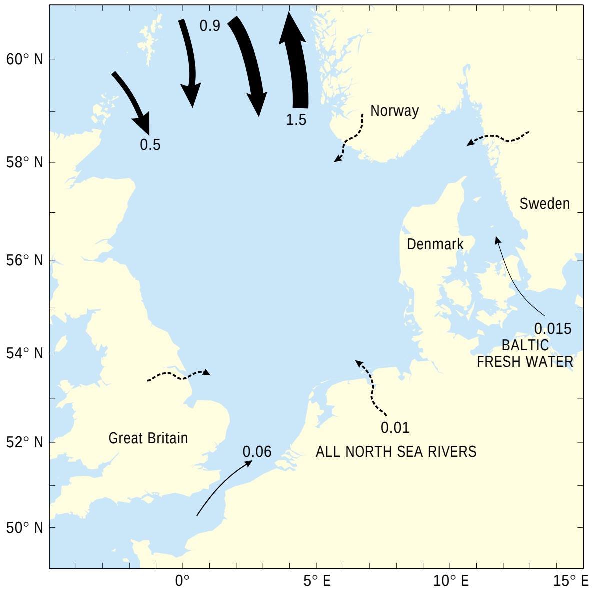
The amount of water leaving the North Sea along the Norwegian coast is estimated at 1.3 – 1.8 Sverdrup (Otto *et al*., 1990). The latest model results from the years 1955–98 indicate seasonal (1st – 4th quarter) average transports of: 1.5, 0.9, 1.1 and 1.4 Sverdrup, with a maximum of about 2.5 Sverdrup during the winters of 1990, 1991 and 1994. These estimated outflows that vary seasonally are in close balance with similar estimates of all the inflows to the North Sea, including the rivers. The net seasonal average inflow through the Channel was modelled to be: 0.05, -0.01, 0.02 and 0.05 Sverdrup for the same quarterly periods *(Figure 2.14)*. The mean transport passing through the Skagerrak, estimated from observations, is 0.5 – 1.0 Sverdrup (Rodhe, 1987; Rydberg *et al*., 1996), of which 50% is in the surface waters. Recent modelling exercises indicate even higher transports especially during winter.

Estimating mean water transport in the North Sea from traditional measurements is made difficult by the large variability resulting from frequent changes in atmospheric forcing and changes in water density. Climatic variability also causes very large inter-annual variations in water transport. Numerical models have been used to cope with

Table 2.4 Residual flows through the Dover Strait (in Sverdrup) from literature data. Source: Boon *et al*. (1997).

Tide only	Tide + Average wind	Remarks	Source
0.115	0.155	M2 tide	Prandle (1978)
0.050	0.090	Based on Cs-tracer data, wind shear stress = 0.07 Pa	Prandle (1984)
0.037	0.149	Averaged wind speed is SW 8 m/s, wind shear stress = 0.13 Pa	Salomon (1993a)
0.038	0.114	Averaged wind over period 1983-1991	Salomon (1993b)
0.036	0.094	Based on HF radar and ADCP field data	Prandle *et al.* (1996)

Figure 2.14 **Major long term modelled mean (1955–98) influx and outflux volume (in Sverdrup) of the North Sea during winter.**



this large spatial and temporal variability. *Figure 2.15a* shows a 44 year (1955–98) time series of modelled inflow (mainly of Atlantic Water) to the northern North Sea during winter along an east-west section between Norway and the Orkney Islands (59° 17' N). The inter-annual variability was typically between 1.7 and 2.3 Sverdrup. However, in the period 1988–95 (except 1991), inflows were significantly higher indicating quite different atmospheric conditions. The latter has also been revealed in extreme wave height measurements during this last decade. The predominant flow through the Dover Strait is from west to east, but models also indicate that during spring net flux may be close to zero.

A comparison between several models calculating flushing times of water in several subregions of the North Sea *(Table 2.5)* clearly demonstrates that the large scale models agree to a considerable extent, and that transport calculated from hydrographic and sporadic current observations can be significantly underestimated. This is particularly the case for the central North Sea and the English coast where the ICES flushing time estimates are of the order of 10 times longer than the model results (Backhaus, 1984; Lenhart and Pohlmann, 1997).

The flushing time for the entire North Sea, including the Norwegian Trench, is estimated to be about 1 year, whereas it is only 4 months for the Norwegian Trench part (Otto *et al*., 1990). Recent modelling/observation studies of ^{137}Cs discharges from Sellafield and atmospheric inputs resulting from the Chernobyl accident indicate flushing times of approximately 500 days for the North Sea.

Using ^{125}Sb and ^{137}Cs as tracers, transit times from Cap de la Hague were estimated to be of the order of 2 – 4 months to the Strait of Dover and 6 – 8 months to the western German Bight *(Figure 2.13)*. These transit times are short compared to the modelled flushing times in Table 2.5 and a flushing time for the whole North Sea of about one year.

Other results from simpler model experiments tend to give flushing times that are too long (or transports that are too weak). It should be noted that in some regions, the flushing times of deep water may be much longer than in near-surface water. For example, in the Skagerrak the flushing time is of the order of years for deep water and of months for surface water. This, together with the fact that large seasonal and inter-annual variations occur, indicates that such estimates of average flushing times must be used with care.

While these values may be useful for estimating average concentrations of widely dispersed material such as nutrients derived from the Atlantic, they may have little relevance for estimating peak concentrations in situations where the local circulation close to a specific contaminant

Figure 2.15 **Time series of modeled volume transports in the period 1955–99: (a) into the northern North Sea between Norway and Orkneys during winter (first quarter), (b) net into the North Sea through the English Channel during spring (second quarter). Source of data: Skogen and Svendsen.**

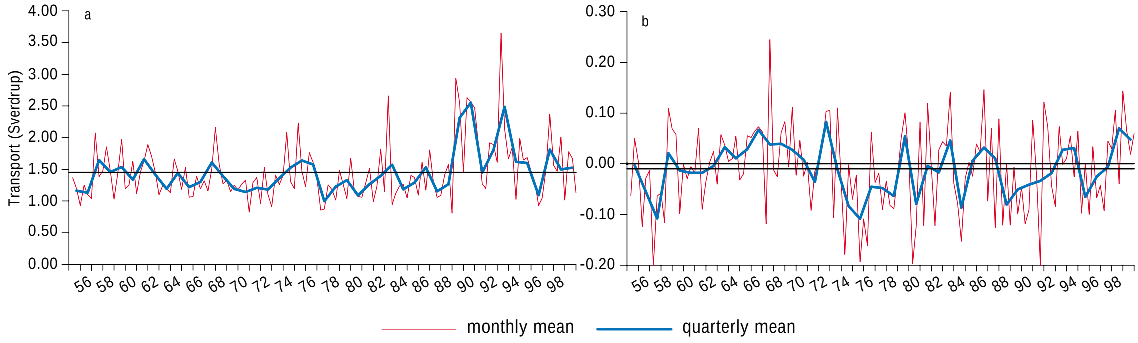
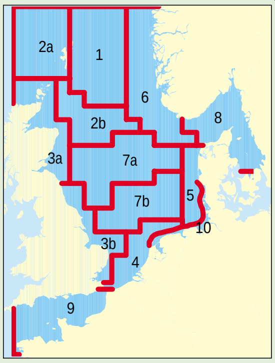


Table 2.5 Comparison of flushing time (days) calculations from three numerical models and derived from measurements. Source of data: Backhaus (1984), ICES (1983), Lenhart and Pohlmann (1997), Skogen *et al*. (1995).



Subregion	Volume (km^3)	Model 1* Minimum	Model 1* Maximum	Model 1* Mean	Model 2 # Minimum	Model 2 # Maximum	Model 3 † (1 year, 1985)	ICES Mean
1	6 345	21	50	38	35	48	43	142
2b	5 644	14	49	28	9	39	50	109
6	12 815	20	57	38	41	61	63	76
7a	6 190	19	68	40	32	49	89	–
7b	2 770	13	57	34	31	39	65	547
3a	3 176	18	73	36	13	41	54	–
3b	1 138	10	50	30	15	30	48	464
4	1 323	7	49	28	21	29	50	73
5a	602	10	56	33	10 §	27 §	32 §	73 §
5b	404	2	29	11				
8	–	–	–	–	–	–	131	–

* Lenhart and Pohlmann (1997) # Backhaus (1984)

† NORWECOM, Skogen *et al*. (1995) § These models make no subdivision between subregions 5a and 5b.

source (e.g. coastal trapping) may be crucial. For short-term phenomena of the order of days, such as plankton blooms, peak concentrations may be more sensitive to vertical exchange rates and relatively independent of the horizontal circulation (Prandle, 1990).

2.11.4 Gyres/eddies

Satellite images of the sea surface temperature invariably indicate numerous vortex-like or rotary movements on a range of scales, known as gyres or eddies. Infrared satellite images in particular *(Figure 2.11)* show that eddies are a common feature throughout the North Sea. They are considered an important cause of the generally observed patchiness of biota and biological processes.

Eddies may be transient, generated along frontal boundaries, or stationary, generated by topographical features. Small eddies have been observed along the Flamborough Front, located off Flamborough Head on the east coast of England. A much larger topographically generated eddy may be found to the north of the Dooley Current. More transient but very energetic eddies (typically 50 km in diameter and 200 m in depth, with a maximum current speed of about 2 m/s) are frequently found along the frontal zone of the Norwegian Coastal Current *(Figure 2.11)*. Their origin is uncertain, but they may be generated partly by topography and partly by the pulsating outflow from the Skagerrak.

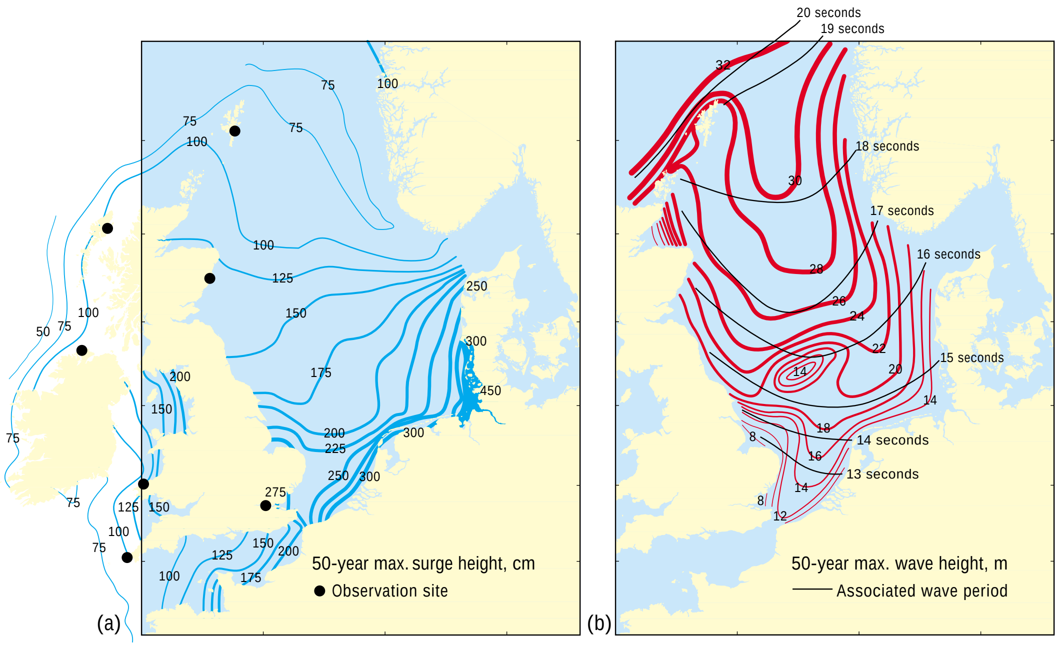
2.12 **Waves, tides and storm surges**

2.12.1 Waves

During storms, the resuspension and vertical dispersion of bottom sediments due to waves and currents is a process that affects most of the North Sea, except for the deepest areas of the Skagerrak and the Norwegian Trench. Understanding this process is clearly important to the development of realistic studies of the variability in contaminant concentrations and transport. It is also important to understand the processes of wave-current interactions that can produce abnormal waves, which are potentially dangerous for example, to shipping and offshore structures. In recent years, extreme-wave analysis for specific locations has also been relevant to site selection for fish farms.

Extensive measurements have been made to estimate the wave climate of the North Sea *(Figure 2.16)*. Wave-spectrum models are operated routinely, also in conjunction with atmospheric forecasting models. Some statistical investigations show that almost all indicators representative of storminess indicate no worsening of the storm climate for the North Atlantic Ocean and the adjacent seas (von Storch, 1996). On the other hand, statistics on significant wave heights for the North-east Atlantic point to a steady increase of the order of about 2 – 3 cm/year over the last 30 years. The inconsistency of both findings may be related to the different time scales considered. Reliable wave measurements have been available only since about 1960, while the storm climate and storm surge time series are typically longer than 100 years. However, from 1960 to about 1990 the North Atlantic Oscillation has increased and so has the wind speed, as measured for example at the west coast of Norway (see *Figures 2.17* and *2.18*). Therefore, the increase in wave heights might be a consequence of the variability in the strength of the zonal atmospheric circulation (Bacon and Carter, 1991; 1993). Large variations in the mean wind direction over the North Sea have been

Figure 2.16 **Estimated 50-year extreme maxima in the North Sea: (a) surge height based on models and observations at indicated sites; (b) wave height: distribution and associated wave period. Source of data: (a) Flather (1987); (b) UK Department of Energy (1989).**



observed (Furnes, 1992) and consequently increased fetch may also be a part of the explanation for the increased wave heights.

2.12.2 Tides

Tides in the North Sea result from the gravitational forces of the moon and sun acting on the Atlantic Ocean. The resulting oscillations propagate across the shelf edge, entering the North Sea both across the northern boundary and through the Channel. Semidiurnal tides (two per day) predominate at the latitudes concerned and are further amplified in the North Sea by a degree of resonance with the configuration of the coasts and depth of the seabed (Vincent and Le Provost, 1988). *Figure 2.19* shows the amplitude and the phase of the tidal wave relative to the moon over Greenwich.

Tidal currents *(Figure 2.20)* are the most energetic feature in the North Sea, stirring the entire water column in most of the southern North Sea and the Channel. In addition to its predominant oscillatory nature, this cyclonic propagation of tidal energy from the ocean also forces a net residual circulation in the same direction. Although much smaller (typically 1–3 cm/s compared with the

Figure 2.17 **Time series of the winter (December to March) NAO index and 5-year running mean (thick line) in the period 1864–1997. Source: adapted from Hurrel (1995).**

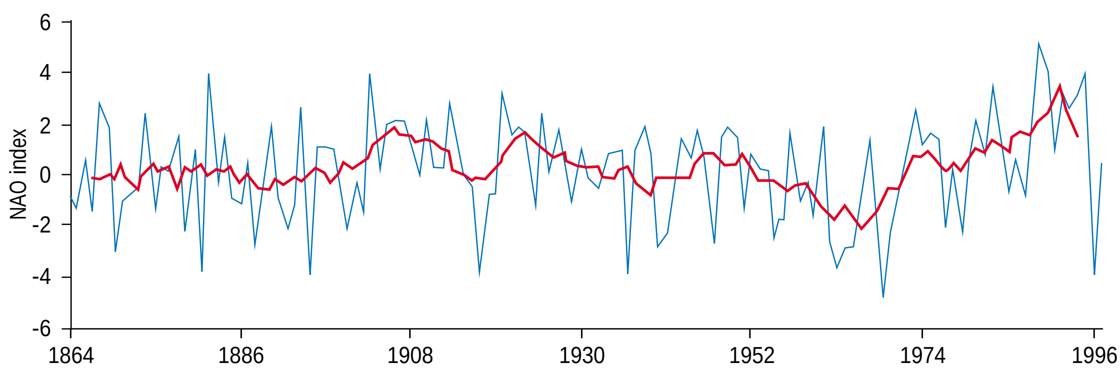
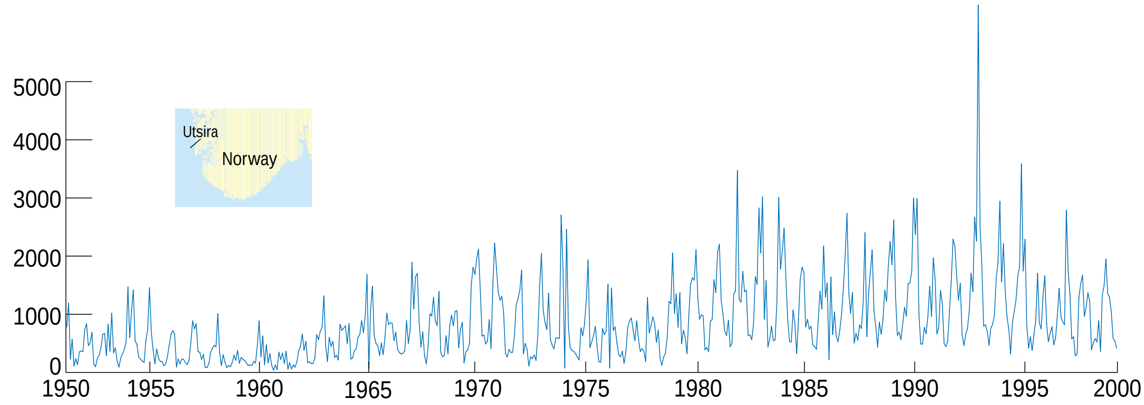


Figure 2.18 **Monthly mean cubed wind speed (in m^3/s) from 6-hourly measurements on the Norwegian coast at Utsira (see inset).**



oscillatory tidal currents exceeding 1 m/s), the resulting net currents are persistent and account for approximately 50% of the water transport in the western North Sea.

Along the coasts, tidal currents are oriented parallel to the coast and the exchanges between coastal and offshore waters are limited. For example, riverine waters and the associated suspended particulate matter (SPM) remain close to the French coast, and move slowly northward through the Strait of Dover into the Southern Bight (Dupont *et al*., 1991). In certain cases the frontal region between the coastal and offshore waters is much reduced during neap tides compared to spring tides, causing significant variability in the exchange of SPM between coastal and offshore waters.

In stratified waters, the tides can generate internal waves that propagate along the interface between the two layers. These waves can have important biological effects, as a result of enhanced vertical mixing where such waves break as well as the oscillatory movement of biota into the euphotic zone via the often large vertical displacements involved.

A large tidal range is an important condition for economic tidal power generation. Tidal heights are greatly amplified in the bays along the French coast of the Channel where heights of 8 m and more are not uncommon. Estuaries in these regions are characterised by vast intertidal zones of both mud and sand, where highly mobile sediments tend to block river mouths.

Locally, extensive construction work and the deepening of navigation channels to major ports may have a strong effect on tidal propagation. For instance, observations from tide gauges in the rivers Elbe, Weser, and Ems reveal that the attenuation of tidal waves has decreased and that the travel time of tidal waves has shortened.

2.12.3 Storm surges

Storm surges can occur in the North Sea, especially along the Belgian, Dutch, German and Danish coasts during severe storms. They sometimes cause extremely high water levels, especially when they coincide with spring tides.

Numerical models are operated routinely in conjunction with atmospheric models and provide accurate predictions (± 30 cm in 90% of the cases) of flood levels. Another method relies on statistical methods and involves tracing and modelling systematic correlations within one or more series of water level measurements. These two techniques can also be used in tandem, while at the same time employing the latest data from the monitoring stations located at offshore platforms and coastal stations, in order to update the model or the predictions. This is called

Figure 2.19 **Mean spring tidal range (co-range lines in m) and co-tidal lines at time intervals referred to the time of the moon's meridian passage at Greenwich.**

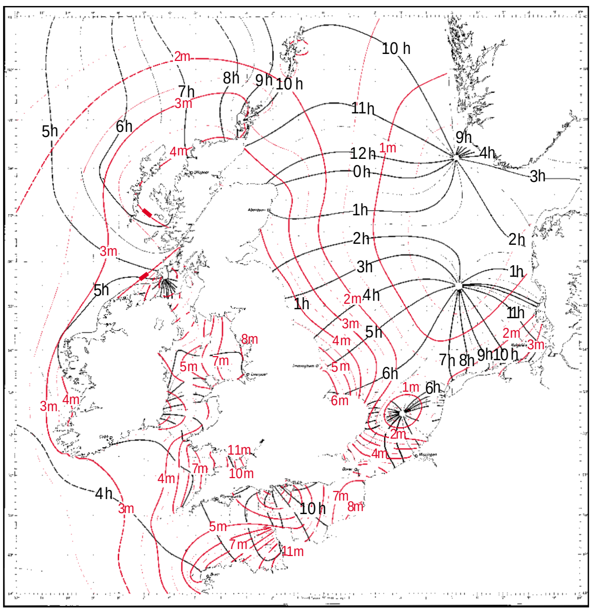
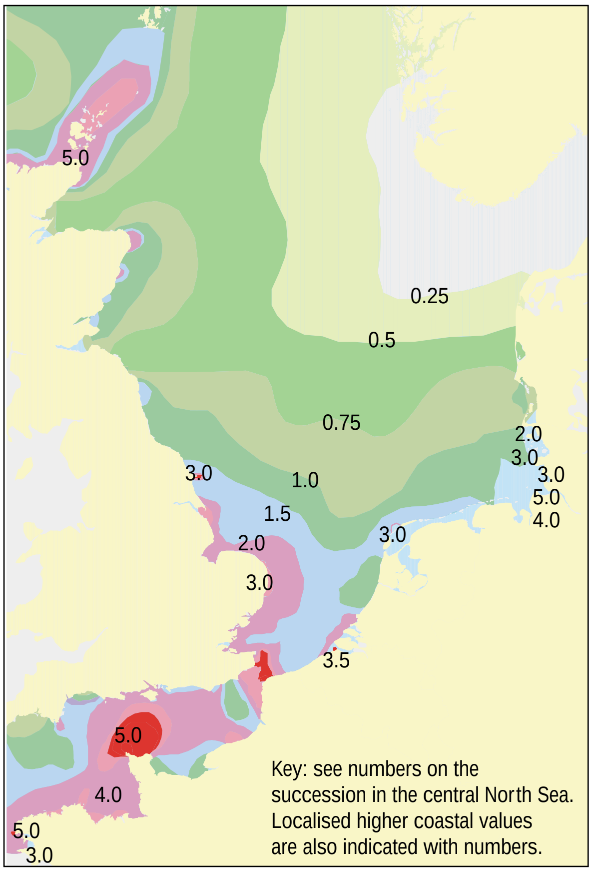


Figure 2.20 **Contours of maximum tidal stream amplitudes in knots (ca 50 cm/s) at average spring tides.**



assimilation and is used for example by the Dutch organisation for flood control (Philippart and Gebraad, 1997). The increase in storm surge levels is due to an increase in the annual mean sea level and not due to changes in the intensity of high-frequency atmospheric events (Annutsch and Huber, cited in von Storch, 1996). Over the last 100 years an increase in sea level of between 20 and 30 cm was observed for the Dutch coast and the German Bight respectively based on annual means.

2.13 Transport of solids

In the shallow parts of the North Sea, intensive sediment movements and associated sediment transport occur frequently, owing to wind-induced currents, tides, and/or wave action. Sea swell is an especially effective agent for resuspension. This leads to changes in seabed topography and may also result in resuspension of contaminants adsorbed to settled particulate matter and their transportation, and deposition elsewhere.

Due to the nature of the material and the quite different time scales involved, the transport and sedimentation of suspended particulate matter and the erosion of fine sediments are difficult to distinguish and to monitor. The use of transport models is more and more common practice in the process of decision making, and in coastal zones in particular, the impact of dredging activities, land reclamation, new discharge locations, etc., is evaluated by running different scenarios of these numerical models. The development of coupled hydrodynamic and transport models has made it possible to simulate the areas of SPM deposition and fine sediment erosion in the North Sea. However, considerable effort is still required to properly validate such model results. Averaged simulations for 1979, 1985, and 1986 are shown in *Figure 2.21*. The deposition rates determined by this model can be compared with observed sediment accumulation data. There is satisfactory agreement between empirical and model results for the northern North Sea (Fladen Ground) and south of the Dogger Bank. However, for the Skagerrak, the model predicts that the highest deposition rates should occur on the southern slope, whereas field measurements show that the highest rates are in the north-eastern sector (Pohlman and Puls, 1983). *Table 2.6* gives details of the amounts of particulate material transported annually in the North Sea. Particulate matter originating from external sources (such as adjacent seas, rivers, dumping, cliff erosion) contributes to a yearly average of about 24 x 10^6 t deposited in the North Sea.

CLIMATE

2.14 Meteorology

The North Sea is situated in temperate latitudes with a climate that is strongly influenced by the inflow of oceanic water from the Atlantic Ocean and by the large scale westerly air circulation which frequently contains low pressure systems. The extent of this influence varies over time, and the winter North Atlantic Oscillation (NAO) Index (a pressure gradient between Iceland and the Azores) governs the strength/persistence of westerly winds *(Figure 2.17)*. The most extreme decadal change since the 1860s has occurred from about 1960 up to the present, with very weak westerly winds during the 1960s and very strong westerly winds during the early 1990s.

Although atmospheric circulation has intensified during the last decades, it is not obvious that this is the case on a time scale of 100 years. This relates to the severe weather experienced particularly during the early part of the 20th century (WASA Group, 1998), also indicated by the NAO Index *(Figure 2.17)*.

The persistence/strength of the westerly winds has a significant effect on water transport and distribution, vertical mixing and surface heat flux. This atmospheric

Figure 2.21 **Erosion and deposition of sediments in the North Sea. Computed annual erosion and deposition of fine sediments in the North Sea (average of three years: 1979, 1985, 1986).**

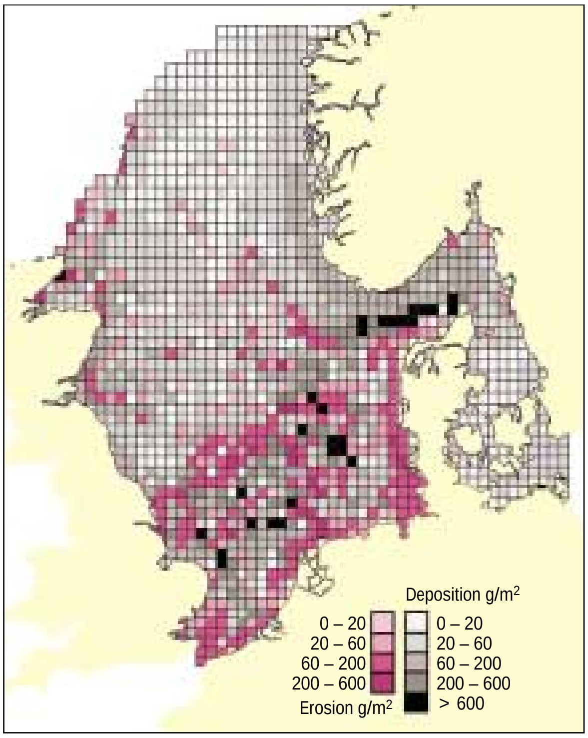


Table 2.6 Supply, outflow and bottom deposition of suspended particulate matter in the North Sea (Eisma and Irion, 1988).

	10^6 t/yr	
Supply		
North Atlantic ocean	10.4	
Channel	22 – 30	
Baltic	0.5	
Rivers	4.8	
Seafloor erosion	*ca.* 9 – 13.5	
Coastal erosion	2.2	
Atmosphere	1.6	
Primary production	1	
Total supply		*ca.* 51.5 – 64
Outflow	*ca.* 11.4 – 14.3	
Deposition		
Estuaries	1.8	
Wadden Sea and The Wash	5	
Outer Silver Pit	*ca.*1 – 4	
Elbe Rinne	?	
Oyster Ground	*ca.* 2	
German Bight	3 – 7.5	
Kattegat	8	
Skagerrak and Norwegian Trench	*ca.* 17	
Dumped on land	2.7	
Total outflow and deposition		*ca.* 51.9 – 62.4

circulation is also closely related to cloud cover and therefore the light conditions in the water. All this has been shown to especially strongly affect productivity and recruitment, growth and distribution of fish stocks (Svendsen *et al*., 1995).

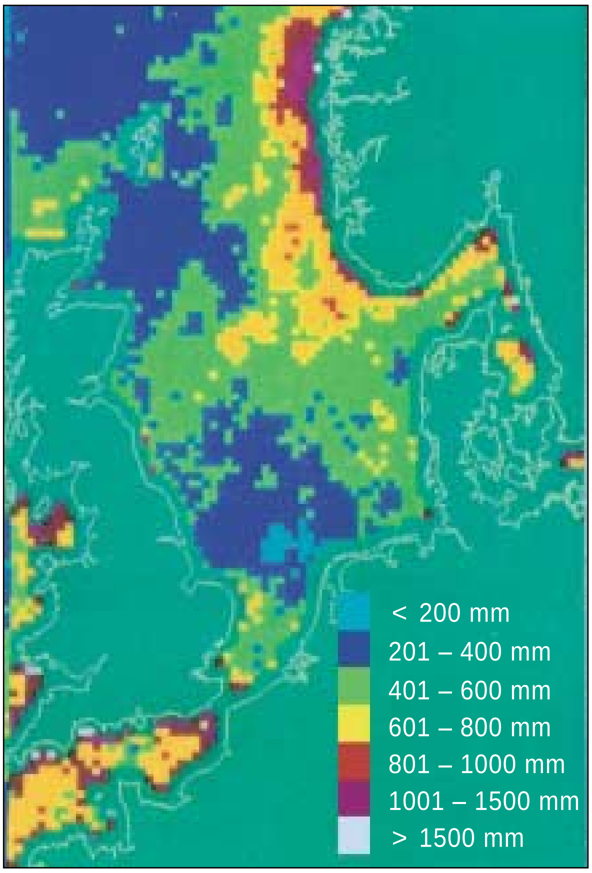
Figure 2.18 shows the monthly mean cubed wind speed, a measure of the energy input to the ocean from wind, from 6-hourly measurements taken since 1950 at an island west of Norway (Utsira). In addition to the well known large seasonal variability, very large variations have occurred in the wind field, and an increasing trend in the wind speed, which is in qualitative agreement with the NAO index, has been noted from the early 1960s until today (but broken by a calm period in the late 1970s). Large variations in mean wind direction over the North Sea have also been observed (Furnes, 1992). Their importance in driving the inflows to and outflows from the North Sea has been clearly demonstrated (see below and *Figure 2.15)*.

As a result, the North Sea climate is characterised by large variations in wind direction and speed, a high level of cloud cover, and relatively high precipitation. Rainfall data *(Figure 2.22)* (Hardisty, 1990; Barrett *et al*., 1991; ICES, 1983) show precipitation ranging between 340 and 500 mm per year, and averaging 425 mm per year. High levels of precipitation occur along the Norwegian coast (about 1 000 mm per year) as a result of wind-forced uplift of moist air against high, steep mountain ranges. There is roughly a balance between direct rainfall and evaporation.

2.15 Ocean climate variability

Only few really long temperature and salinity time series exist for the Greater North Sea. However, none of these series are without considerable gaps in observations. One of the longest series consists of the data from Helgoland in the inner German Bight. Observations began in the 1870s and have continued until the present day. Data gaps, especially between 1945 and 1960, were filled with corrected data from a nearby Light Vessel. Both time series *(Figure 2.5)* show a remarkable annual, inter-annual and decadal variability. The SST series show a weak positive trend which is in agreement with the global temperature increase of about 0.6 °C/100 yr. The salinity shows no significant trend over the 120 years of observations, indicating a rather stable ratio between the advection of saline water from the North Atlantic into the North Sea and the continental run-off, here mainly from the Elbe and Weser drainage area.

Figure 2.22 **Mean annual rainfall over the North Sea estimated from Nimbus-7 passive microwave imagery, calibrated by UK radar for 1978–87.**



The main causes of long-term (season to 100 years) variability in the North Sea temperatures are fluctuations in surface heat exchange, wind field, inflow of Atlantic water, and freshwater input. Clearly, winter cooling has a strong effect on the water temperature of shallow regions of the North Sea, and in highly stratified areas of the Skagerrak and Kattegat where the brackish water freezes in cold years. Variable winter cooling may vary the minimum temperature of the deeper water of the northern North Sea by about 2 – 3 °C, which may be important for example for the Skagerrak bottom water renewal (Ljøen, 1981). The time series of temperature, salinity and oxygen at 600 m depth in the Skagerrak from 1952–99 illustrate the magnitude of these changes *(Figure 2.23)*.

The variable heat input that occurs during summer is important in relation to the surface temperature, but it is relatively less important for deeper waters since the stability created during heating (thermocline) effectively prevents vertical heat exchange. Climatic changes in the North Sea can often be discerned in the temperature and salinity characteristics of bottom water masses (Svendsen and Magnusson, 1992).

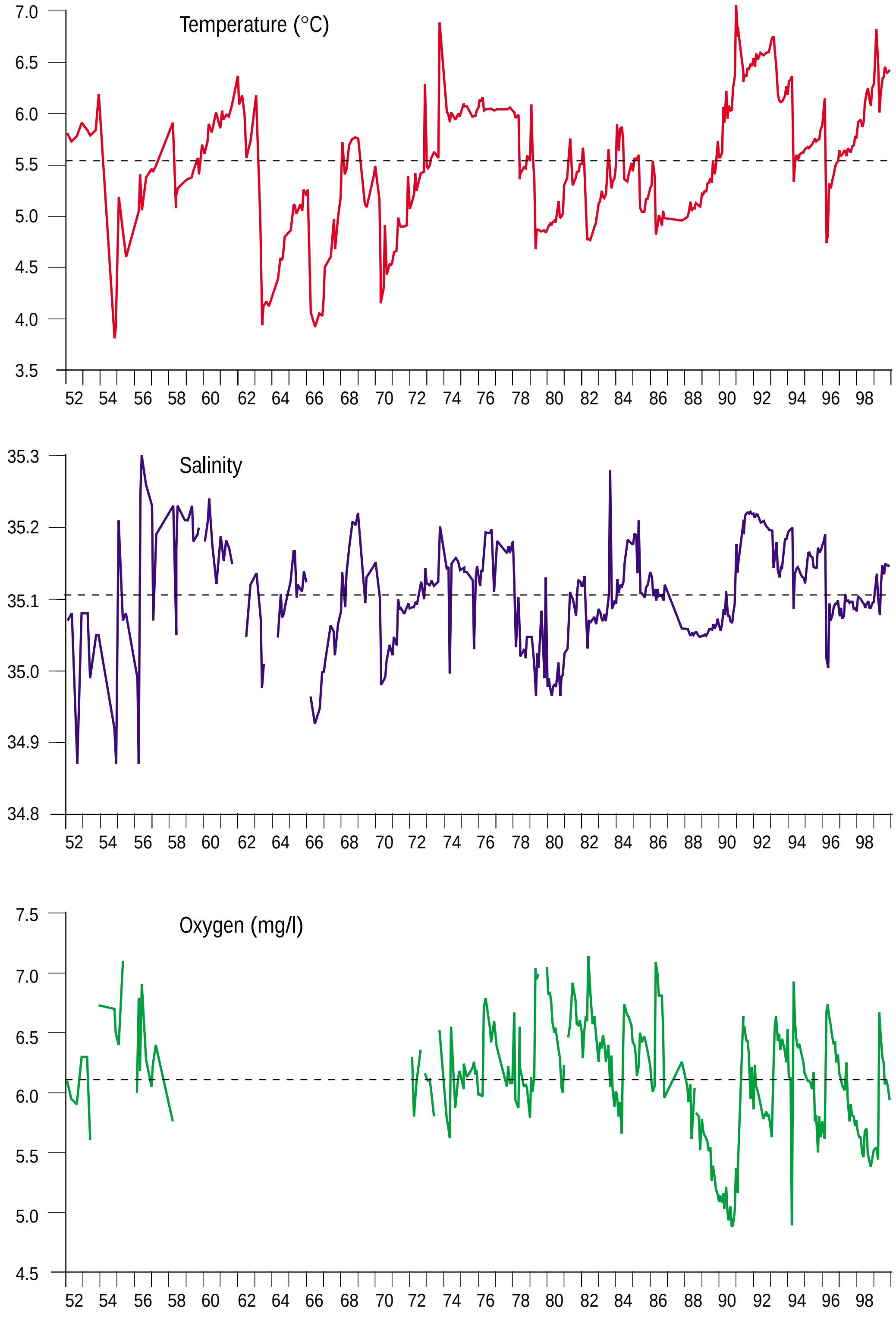
It has been demonstrated by large amounts of hydrographic and meteorological data available for 1968–90 that the winter cloud cover is important in determining the heat content of the northern North Sea (Svendsen and Magnusson, 1992). The heat content is also strongly affected by large year-to-year variations in the inflow of relatively warm (during winter) Atlantic water, as was modelled for the years 1955–97 (see *Figure 2.15*). The influence of Atlantic water is important for general circulation in the northern North Sea and the Skagerrak. As Atlantic water is the main source of nutrients and the supply of plankton for the North Sea, this variable inflow from year to year, combined with a variable wind climate (causing an upward flux of nutrients) and heat content, is the main factor determining biological productivity in large areas of the North Sea. These climatic variables have been demonstrated to influence, directly or indirectly, the recruitment of several fish species in the North Sea (Svendsen *et al*., 1995). It has also been demonstrated that the variable inflows directly affect the migration of adult fish into the northern North Sea (Iversen *et al.*, 1998).

While the winters of 1989 and 1990 appear to have been the mildest for the North Sea in the last 50 years (perhaps even the last 130 years), 1977–9 and possibly 1942 were probably the coldest. The 1977–9 cold period was associated with very weak winds and a low influx of Atlantic water to the North Sea, and has, in turn, been associated with the well-known late 1970s salinity anomaly (Dickson *et al*., 1988). This anomaly was a clear large-scale North Atlantic phenomenon that strongly affected all northern ocean areas, including their biology. Global models are now being developed with the objective of predicting ocean climate by means of sophisticated numerical simulations of circulation and heat exchange. The validity of such models will be demonstrated by the degree to which they can correctly simulate these extreme events.

Clearly, the extremely warm period in 1989–90 (remaining relatively warm up to 1995) is connected to the strong inflows of Atlantic water during the winters of this period (except 1991, *Figure 2.15a*). From continuous monthly mean modelled time series it has also been shown that the variability in transport has increased in the north which is in agreement with the increased strength and variability in wind speed shown in *Figure 2.18*.

Between the late 1930s and the mid-1980s, the general trend in the surface atmospheric temperature and the mean ocean temperature of the upper 30 m in Norwegian coastal waters was a decrease of about 2 °C. In deeper waters, no such clear trends have been observed. As a consequence of increasing concentrations of greenhouse gases in the atmosphere, radiation processes can be expected primarily to raise sea surface temperatures globally. However, the climate system, with its manifold components and positive and negative

Figure 2.23 **Variations in the temperature, salinity and oxygen of the bottom water (600m depth) in the Skagerrak for the years 1952–99.**

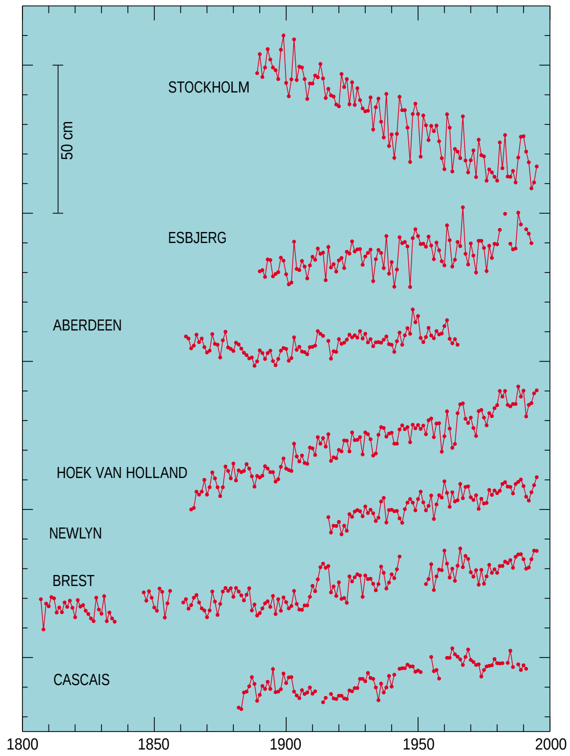


feedback mechanisms, cannot be predicted with certainty. As an example, the role of the oceans is, on the one hand, likely to delay overall temperature changes, but on the other, to enhance local scenarios because of possible changes in ocean circulation. It is assumed that north-western Europe will be an area of less rapid warming than more continental regions. At present, there are no strong indications of rapid warming except in the very deep waters of the Norwegian Sea due to reduced deep water formation.

The average rate of increase of Mean Sea Level (MSL) over the last century, as determined from tide gauge data, is of the order of 1 – 2 mm/yr at most stations. An example of the increased sea level from several stations in Europe is given in *Figure 2.24*. Weaker or even negative trends are observed in Scotland and Sweden, and larger increases have occurred around the German Bight, in the Wadden Sea and Dutch coastal zone, in south-eastern England, and at mid-Channel ports in England and France. The spatial pattern is similar to that determined from geological data averaged over several thousand years, indicating a tilting of the land masses.

The Intergovernmental Panel on Climate Change (IPCC) has reported that it is difficult to determine the possible regional effects of climate change (IPCC, 1996). However, in the period until the year 2100, their most probable estimates for the north-eastern Atlantic areas are a surface air temperature increase of about 1.5 °C, a sea level rise of about 50 cm and a general increase in storminess and rainfall. Since the 1960s the NAO has shown the largest increase since the beginning of measurements in the 1860s, and reached an all time decadal maximum around the early 1990s *(Figure 2.17)*. However, proxy data (from the close correlation of winter tree growth with the winter NAO index) some thousand years old, indicates several occasions when similar increases have occurred, the most recent over the last 30 years. Also paleoclimatic data show that very rapid climate changes have occurred in the North Atlantic regions over time scales of 10 to 100 years. There is now considerable speculation as to whether climate changes will take place over the next few decades and, if so, in

Figure 2.24 **Representative long-term records of relative sea level along North-east Atlantic and Baltic Sea coastlines.**



what direction. There is as yet no real method for predicting the effects that climate change might have on the North Sea ecosystem. In order to better understand the mechanisms, it is very important, therefore, that long-term monitoring of key physical (e.g. temperature and salinity), chemical (e.g. dissolved CO_2 and oxygen) and biological (e.g. plankton species) variables are continued under the auspices of the relevant intergovernmental organisations. The availability of such data will make it possible to detect trends above the noise due to the natural (short-term) variability of the ecosystem. This, in turn, will lead to more precise information on the ultimate effect of climate change on the North Sea ecosystem.

chapter 3

Human activities

3.1 Introduction

This chapter provides an outline of the most important human activities that need to be taken into account in assessing the present quality status of the Greater North Sea. Economic statistics are not aggregated on geographical scales that are appropriate for this assessment report and therefore no information is presented in economic terms.

The countries bordering the Greater North Sea carry out within it major fishing activities, the extraction of sand and gravel, offshore activities related to the exploitation of oil and gas reserves including the laying of pipelines, and use it as a transport route and for dumping dredged material. The North Sea is one of the most frequently traversed sea areas of the world. Two of the world's largest ports are situated on the North Sea coast, and the coastal zone of the Greater North Sea is used intensively for recreation.

The Greater North Sea is surrounded by densely populated, highly industrialised countries. As a consequence, the area is affected by industrial, domestic and agricultural activities, which create inputs, via various pathways, of nutrients, hazardous substances and radionuclides.

In order to reduce the stress on the environment, measures have been adopted to reduce emissions, discharges and losses of hazardous substances, radioactive substances, and nutrients. Measures address point sources such as industries (land-based and offshore) or treatment plants and diffuse sources such as agriculture. In the shipping sector, mandatory routeing measures have been imposed in order to lower the risk of accidents. A number of measures have been introduced and are being further developed concerning the fisheries sector with the aim of achieving sustainable fisheries.

The Convention on the Law of the Sea recognises three areas. The 'territorial sea' generally extends 12 nautical miles offshore and is subject to coastal state jurisdiction. The 'exclusive economic zone' (EEZ) extends 200 nm (350 nm including the continental shelf) and in this zone the coastal state has the exclusive right of exploitation of resources, including fisheries, and is responsible for regulating pollution from sea-bed installations, dumping, and other activities. The 'open sea' beyond the EEZ is not subject to national jurisdiction.

Most of the North Sea States have declared an EEZ and have EEZ legislation in place. This is in preparation in The Netherlands, and the UK has an equivalent area of UK controlled waters. The North Sea States which are EU members have transferred most of their exclusive rights on fisheries to the European Commission.

Following the adoption of the Geneva Convention on the Continental Shelf (1958), the delimitations of the continental shelf were agreed *(Figure 2.1)*. The Netherlands and Belgium agreed on their mutual boundary in 1996.

The framework for the environmental protection of the North Sea has developed extensively over the past 20 years. It includes the International Conferences on the Protection of the North Sea, the OSPAR Convention as the successor to the former Oslo and Paris Conventions, the Bonn Agreement, the Trilateral Governmental Wadden Sea Conferences and also initiatives within the International Maritime Organization (IMO) and the European Community (EC). The North Sea may also benefit from measures taken under the auspices of the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area and from the experience of the Barcelona Convention for the Protection of the Mediterranean Sea against Pollution. Additionally there is co-operation in the framework of international river conventions, such as for the Elbe, Rhine, Scheldt and Meuse.

Protection and conservation of ecosystems and biological diversity of the marine area is now under the new Annex V to the OSPAR Convention, adopted in 1998.

3.2 Demography

Approximately 184 million people live within the catchment area of the Greater North Sea *(Figure 3.1; Table 3.1)*. Since the mid-eighties, international migration has influenced the size of the population, and in 1995 accounted for 80% of the growth of the population of the European Union (EU). In 1996, about 1.5 million people migrated into the catchment area (Eurostat 1997a, Fischer Weltalmanach, 1999). Extrapolating present trends in birth and death rates, and migration, the EU population is projected to reach a maximum in 2025 (Eurostat, 1997b). Considerable changes following the end of the east-west bloc division has resulted in a substantial increase in trade and road transport. The number of people in the coastal regions of Region II varies substantially on a seasonal basis due to tourism.

Figure 3.1 **Catchment area of the Greater North Sea showing the main river systems and areas of high population density. Source: from Grote Bosatlas (1988) as in North Sea Task Force (1993).**

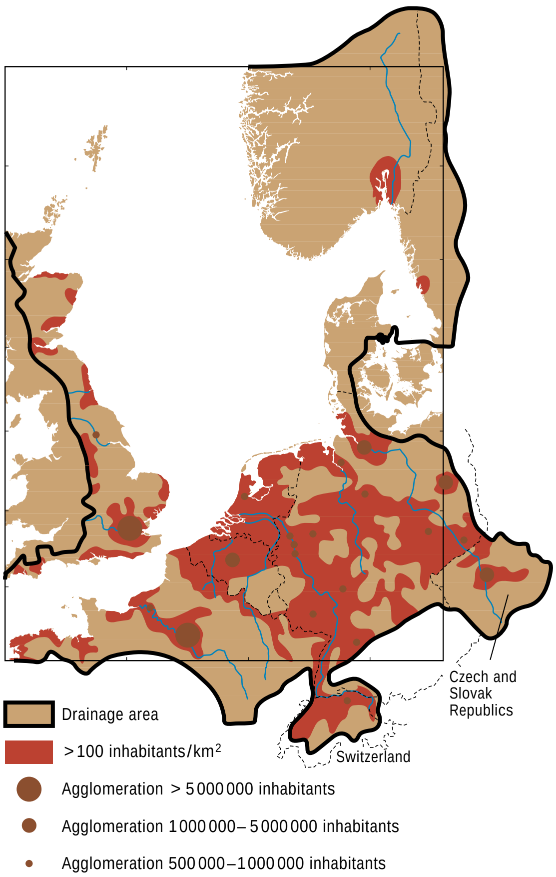


Table 3.1 **Estimated population of the catchment area of the Greater North Sea and population density within the whole country. Source of data: Eurostat, Britannica (1999).**

Country	Population in the Greater North Sea catchment area (x 10^6 inhabitants)	Population density (persons/km²)
Belgium (1996)	10.1	334
Czech Republic (1996)	10.3	131
Denmark (1997)	2.2	122
France (1995)	25.3	107
Germany (1996)	72.5	229
Liechtenstein (1996)	0.16	194
Luxembourg (1996)	0.4	161
Netherlands (1996)	15.6	382
Norway (1997)	3.3	14
Sweden (1995)	2.4	22
Switzerland (1995)	5.7	172
United Kingdom (1995)	36.4	241
TOTAL	184.23	

Note: All data are calculated from Eurostat data, except for Denmark, Norway and Sweden.

3.3 Conservation

3.3.1 Ecological conservation

The Greater North Sea supports a rich coastal and marine wildlife, and has a number of important habitats *(Table 3.2)*. Since a number of species and habitats are endangered, certain areas such as the Wadden Sea have already been given the status of conservation sites in order to allow for protective measures.

Man made modifications to parts of the region have been accompanied by changes and losses of habitats and disturbed ecological functions. In The Netherlands few tidal rivers remain, in Germany a barrier is under construction in the river Ems, and in Scotland, over the years, much estuarine habitat has been lost from the major firths and estuaries, such as those of the Forth and Cromarty. Even in the Wadden Sea most estuaries have been modified. There are, however, new policy developments that aim to restore selected estuarine habitats (e.g. Harlingvliet and Scheldt in The Netherlands).

Important instruments for protecting the marine coastal environment are the EEC Council Directives on the conservation of wild birds (79/409/EEC) (which includes designation of Specially Protected Areas) and on the conservation of natural habitats and of wild fauna and flora (92/43/EEC). Within that framework a coherent ecological network of habitats is to be established (NATURA 2000), but proposed areas only range to 12 nautical miles off shore. Under the 1979 Bonn Convention

Table 3.2 Examples of important habitats, their conservation significance and international conventions.

Habitat type and conservation significance	Examples and Conventions (see key below)
Sea cliffs	
Nesting seabirds (puffins, gannets, guillemots, razorbills, shags), maritime plants, and geological exposure	Lummenfelsen, Helgoland (1), Caithness Cliffs (1,2), Foula (1), St.Abbs (1,2), Fair Isle (1), Bempton Cliffs, Ile d'Ouessant, Gullmarsfjord, Sept Iles–Cap Fréhel
Sand dunes	
Distinctive flora and invertebrate fauna, geomorphological systems	Lower Dornoch Firth including Morrich More (2), Invernaver (2), Durness (2), Barry Links (2), North Norfolk coast, Marquenterre, West coast of, Jutland, De Westhoek, Wadden Sea (1,2,3,5,6), Jærstrendene, Listastrendene
Shingle banks	
Distinctive flora and invertebrate fauna, geomorphological systems	Dungeness, Havergate Island and Orfordness, Culbin Sands (2), Spey Bay (2), Estuaires du Trieux et du Jaudy, Sillon de Talbert
Salt marshes	
Breeding waders and seabirds (shelduck, red shank, black-headed gulls), distinctive flora	North Norfolk coast, Minsmere and Walberswick, Wadden Sea (1,2,3,5,6), Het Zwin, Stigfjord, Baie du Mont Saint-Michel
Intertidal mud flats	
Major internationally important feeding areas for four million wading birds and ducks such as knot and oyster catchers, fish nursery areas, harbours, common seal haul-out sites	Firth of Forth (1), Moray Basin Firths and Bays (1,2,3), The Wash, Foulness and Maplin Sands, Chichester and Langstone Wadden Sea (1,2,3,5,6), Baie de Somme, Kurefjord, Presterødkilen (3), Ilene (3)
Subtidal sediments	
Marine grass, eel grass, maerl, rare fish, invertebrate communities	Bluemell Sound, Shetland, Tamar, Lower Humber, Oosterschelde, Aalborg Bay, Gullmarsfjord, Øra, Kosterfjorden, Wadden Sea (1,2,3,5,6)
Subtidal rocks	
Rich invertebrate communities of boreal and lusitanian origin, including sea fans, cup coral	St. Abbs (2), Cap Gris-Nez, Dover to Kingsdown Cliffs, Brittany, Kosterfjorden

(1) Wild Birds Directive 79/409/EEC
(2) Habitats Directive 92/43/EEC
(3) Ramsar Convention
(4) World Heritage Convention
(5) Bonn Convention: Agreement on the Conservation of Seals in the Wadden Sea
(6) Bonn Convention: Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas – ASCOBANS

on the Conservation of Migratory Species of Wild Animals, the African-Eurasian Waterbird Agreement for the protection of migrating water birds aims to protect the most important breeding, feeding, resting and overwintering areas in the African-European region (CWSS, 1998).

Areas that are still in a natural or near natural state require special protection. The Wadden Sea Trilateral Conservation Area is an example, and areas outside the Wadden Sea could be protected under the Ramsar Convention and relevant EC Directives to the extent that they are applicable, or under Annex V of the OSPAR Convention once it enters into force.

As a consequence of the 1988 seal virus epidemic, the Wadden Sea States gave special protection to the common seal (*Phoca vitulina*) population by implementing the 1990 Agreement on the Conservation of Seals in the Wadden Sea under the Bonn Convention. All small cetaceans are protected by the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS) under the Bonn Convention, although Norway does not subscribe to it. Protection and conservation areas will be designated in Scotland (Moray Firth, bottle-nose dolphins (*Tursiops truncatus*)) and in the Wadden Sea (near Sylt, harbour porpoises (*Phocoena phocoena*)).

3.3.2 Archaeological conservation

Part of the floor of the North Sea is submerged land, and in centuries past quite a number of villages in the Southern Bight have been submerged by the sea. Archaeological remains and shipwrecks, although usually well preserved in anaerobic bottom sediments, are subject to disturbance and destruction by mineral extraction, navigational dredging, pipe laying, and pollution.

Special legislation for protecting marine archaeological relics exists in most North Sea countries. The 'European Convention on the Protection of the Archaeological Heritage' regulates sites of Cultural Heritage significance, both on land and in the sea. Moreover a draft Convention on the underwater cultural heritage is under discussion within the UN.

3.4 Tourism and recreation

Tourism in North Sea coastal areas and adjacent land is an important social and economic activity *(Table 3.3)* with developments creating intense pressure on the environment. The numbers of overnight stays and the number of berths in marinas has increased over the last decade. Recreation can mean more pressure on the dynamic processes of the dunes, for example because of the construction of recreational housing, and thus cause disturbances of sea bird habitats. Another effect is littering of the beaches. In order to reduce disturbance, in some areas management policy aims to avoid the development of new marinas and to impose speed limits for boats. Zones where recreational activities (including boating) are forbidden have been established in ecologically sensitive areas.

Tourism has a seasonal pattern and the stress upon the ecosystem is consequently unevenly distributed over the year. For example, in the National Park of the Wadden Sea, 75 – 90% of all overnight stays are booked for the period April-October. In some areas the number of overnight stays per year amounts to more than 20 million, for example in the North Sea area of Denmark 25 million overnight stays were counted in 1996 *(Table 3.3)*, which may be compared with the 2.2 million Danes living in this area.

Table 3.3 Estimates of visitor numbers for the North Sea coast.

Country	One day visitors (10^6/yr)	Overnight stays (10^6/yr)
Belgium (1996)	20	13
Denmark (1996)	No information	25
France	No information	No information
Germany (1996)	No information	21 *
Netherlands (1996)	8.9	13.5
Norway	No information	No information
Sweden (1997)	1.5	19.3
United Kingdom	No information	24

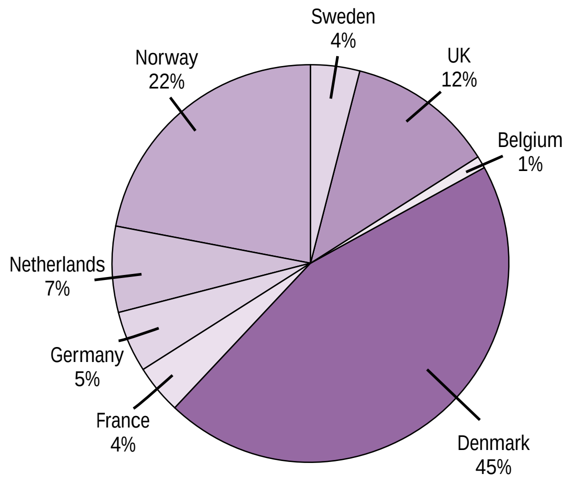
* Listed only lodgings with more than nine beds; camping places and private apartments are not included.

3.5 Fishing

3.5.1 Fish

The North Sea is one of the world's most important fishing grounds. Fishing activities vary in importance in the countries bordering the North Sea ***(Figure 3.2)***. Denmark (45%) and Norway (22%) have by far the largest landings of fish and shellfish (5NSC, 1997). The combined landings of different species in 1995 amounted to 3.47 x 10^6 t ***(Figure 3.3)***, 1.1 x 10^6 t more than reported for 1990.

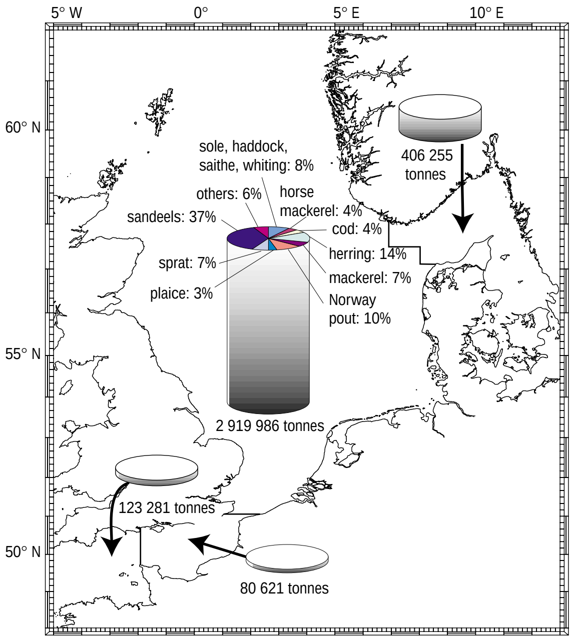
Figure 3.2 **Landings of fish and shellfish from the North Sea, Kattegat, Skagerrak and the Channel by North Sea states in 1995 (% by weight of total). Source: redrawn from 5NSC (1997).**



The species caught for human consumption can be divided into pelagic species that live mostly off the bottom, such as herring (*Clupea harengus*), mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*), and demersal species living on or close to the bottom, e.g. cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), saithe (*Pollachius virens*), plaice (*Pleuronectes platessa*) and sole (*Solea solea*). Landings from industrial fisheries, which account for about 55% of the total landing weight in the North Sea ***(Figure 3.4)***, mainly consist of sand eels (*Ammodytes* spp.), Norway pout (*Trisopterus esmarki*) and sprat (*Sprattus sprattus*) (5NSC, 1997). Landings of four important fish species compared to their pertinent 'total allowable catches' (TAC) for the last 14 years are shown in ***Figure 3.5***.

The gear types used in the North Sea fisheries are demersal active gear (otter and beam trawl, demersal seines), pelagic active gear (purse seines, pelagic trawl), and passive gear (nets, traps, lines). The capacity of

Figure 3.3 **Fish landings from the North Sea in 1995. Source: 5NSC (1997).**



demersal and pelagic fleets in the North Sea increased rapidly after the Second World War and larger ships with more powerful engines came into operation. The total increase in capacity of the fishing fleet occurred mainly in three categories: purse seiners exploiting herring and mackerel; bottom trawlers targeting small demersal and pelagic species, notably sand eel, Norway pout and sprat for fish meal and the fish oil industry; beam trawlers targeting flatfish and roundfish.

There is a general overcapacity in some segments of the fleets fishing in the North Sea. Fishing effort in the entire North Sea rose between 1983 and 1995, attributable largely to increased beam trawl effort in the southern and central North Sea *(Figure 3.6)*. The total fishing effort in 1995 was approximately 2.25 million hours (*Figure 3.7,* Jennings *et al.*, 1999).

There has been a change in the condition of some of the important North Sea stocks over recent years. The herring fishery was closed in the 1970s as the stock was near to collapse at 50 000 t. The stock rebuilt to more than 1 x 10^6 t in 1988. However, fishing mortality was too high and the stock declined rapidly to less than 0.5 x 10^6 t in 1996. Therefore, the TAC was halved in the middle of that year and measures were introduced to restrict the impact of the industrial fisheries (see section 3.5.4). Fishing rates have been maintained at a low level and the stock has increased above 1 x 10^6 t and is expected to exceed 1.5 x 10^6 t in 1999.

The mature stock size of cod was at the lowest level this century in 1993. Since then, it has experienced the highest level of recruitment (young fish) for a decade and the level of fishing mortality has reduced to the lowest level for 30 years. As a consequence, cod is now approaching a safe level of 150 000 t.

Flatfish stocks have declined over the past decade. Plaice levels are low as the high recruitment levels of the 1980s have disappeared and as fishing mortality has steadily increased. Recently, a small increase in stock size has been observed. Fishing mortality has also increased for sole, but several good years of recruitment have steadied the underlying decline (ICES, 1999a).

In addition to direct effects of fishing on target species, there are a number of indirect effects. Lost fishing gear will decay very slowly since it is usually manufactured from

Figure 3.4 **Landings of fish from industrial, demersal and pelagic fisheries and total fish landings from the North Sea from 1903 to 1995. Source: 5NSC (1997).**

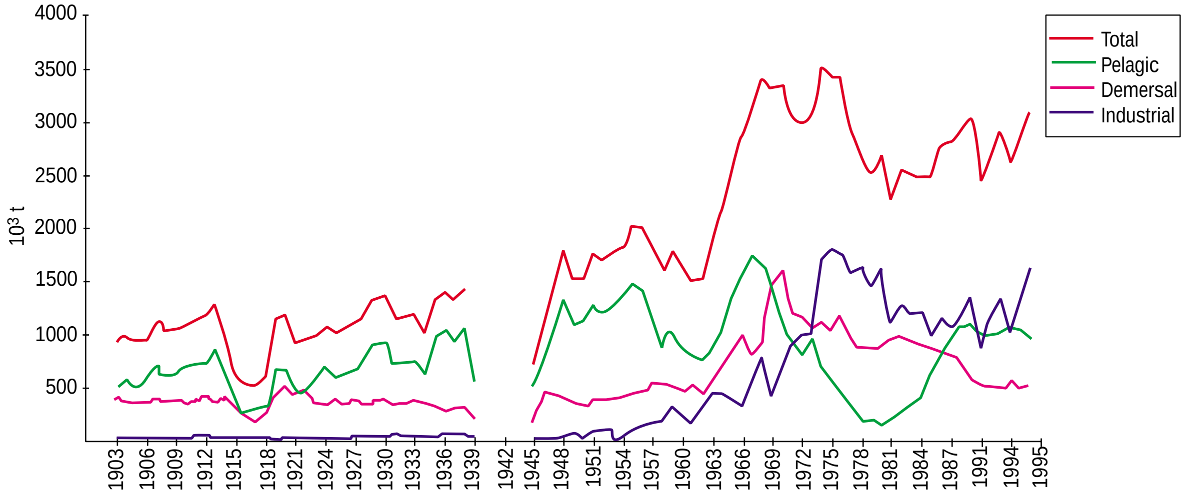
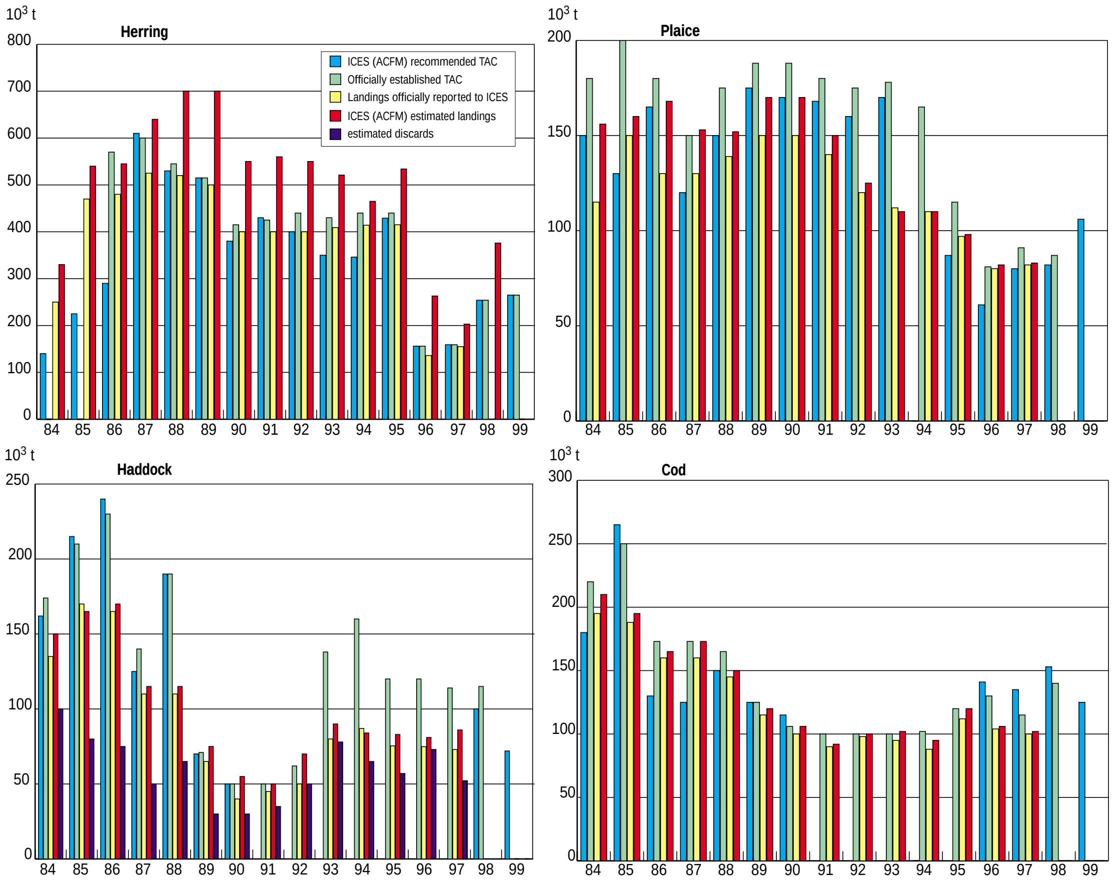
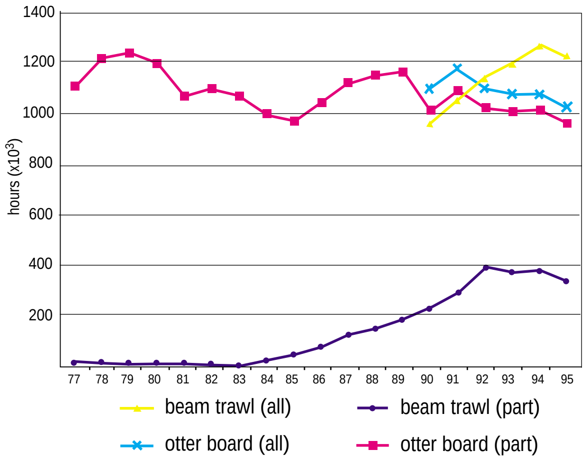


Figure 3.5 **Landings of herring, plaice, haddock and cod 1984–98. Source of data: updated from 4NSC (1995) with data provided by ICES.**



All data refer to landings from fish caught in the North Sea – ICES Division IV (see Figure 5.10)

Figure 3.6 **International fishing effort from 1977 to 1995 for different bottom trawling fishing gear. Source: redrawn from Jennings *et al*. (1999).**

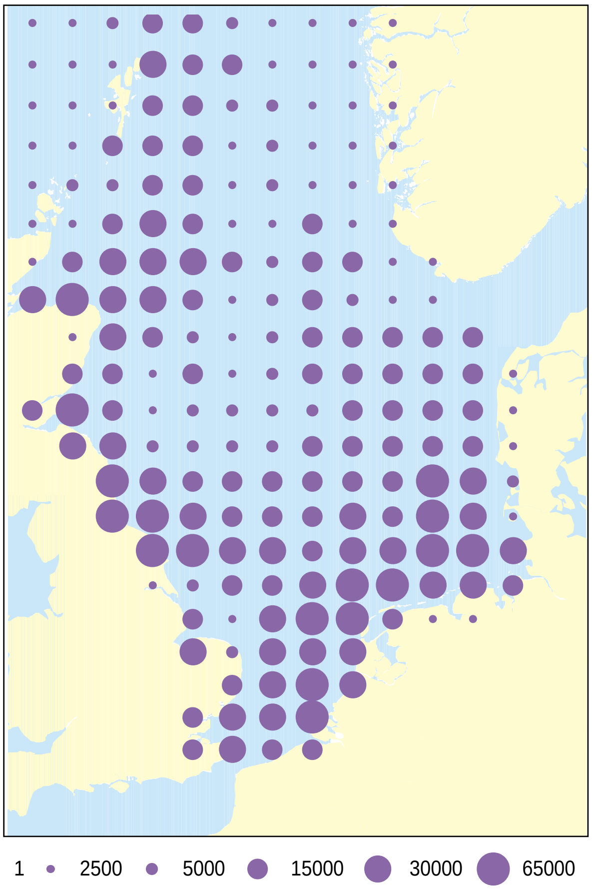


non-biodegradable synthetic material, and organisms may become entangled incidentally (ghost fishing).

Otter trawl boards penetrate 6 – 20 cm into soft seabed sediments and beam trawl tickler chains plough to a depth of 4 – 8 cm. Data from the Dutch beam trawl fleet, which represents approximately 80% of the total beam trawl effort in the North Sea, indicates that about 171 000 km^2 of the North Sea between the Shetland Islands and the Hardangerfjord, and the Strait of Dover (i.e. approximately 429 000 km^2) is fished by trawlers (Rijnsdorp *et al.*, 1997). Within the fished area, 70% is trawled less than once a year and, in total, about 10 % of the North Sea region specified above is fished more than once per year.

The scale of bycatches and other forms of impact varies between the different fisheries *(Table 5.5)*. About 260 000 t/yr of fish are estimated to be discarded in the beam trawl fishery. The estimates for the roundfish fishery are up to 270 000 t/yr for commercial species and 20 000 t/yr for non-commercial species (ICES, 1994). Industrial fisheries using small-mesh trawls account for more than half of the total landings. Probably the most serious threat to the harbour porpoise population is the yearly by-catch of 7 000 individuals in the bottom-set gillnet fishery.

Figure 3.7 **Spatial distribution of mean fishing effort (1990–95) for bottom trawling (in average hours of fishing per year and per square of 1 degree longitude x 0.5 degree latitude). Source: redrawn from Jennings *et al*. (1999).**



3.5.2 Shellfish

The main harvesting methods employed in directed shell-fisheries are dredges, trawls and pots.

Crustacea

The major commercial crustacean in the North Sea is the Norway lobster (*Nephrops norvegicus*) with landings between 12 000 and 20 000 t/yr. Other commercial crustacean species in the North Sea include the northern prawn (*Pandalus borealis*) with landings of about 20 000 t/yr from the Skagerrak/Norwegian Deeps, the Fladen Ground and the Farn Deep, the brown shrimp (*Crangon crangon*) with an average landing around 25 000 t, the edible crab (*Cancer pagurus*), the spider crab (*Maja squinado*) and lobster (*Homarus gammarus*). Crab, lobster and shrimp fishing activities are concentrated in the coastal zones and estuaries (IMM, 1997). The brown shrimp is caught mainly in the coastal zones in and around the Wadden Sea, along the coasts from Denmark to Belgium. Dutch landings of adult shrimp have been increasing since the mid 1970s, while German landings have largely fluctuated around a long-term average of about 10 000 t. Belgian and French landings have fluctuated too, albeit with a general downward trend, whilst Danish and UK landings have fluctuated without a clear trend.

Molluscs

Fishing activities for common or blue mussel (*Mytilus edulis*), cockle (*Cerastoderma edule*), clam species (*Spisula solida, S. subtruncata*), common whelk (*Buccinum undatum*) and winkle (*Littorina littorea*) are concentrated in the coastal zones and estuaries along the entire east coast of England, the French Channel coast and the Wadden Sea *(Figure 3.8)*. Denmark, France and The Netherlands have the greatest total landings.

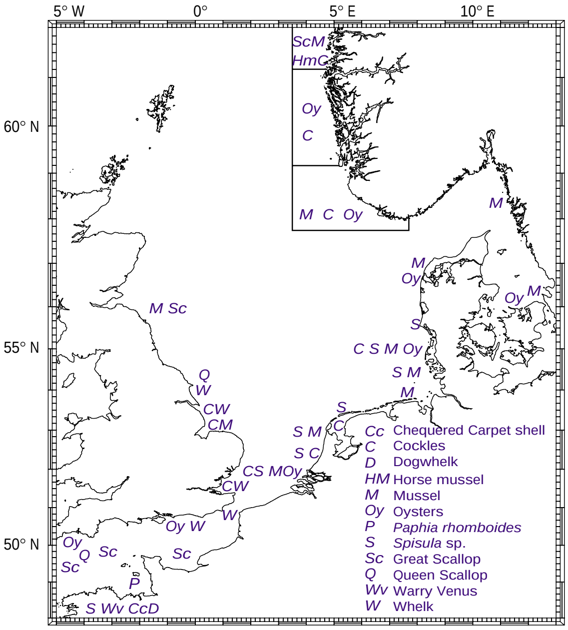
The most important mollusc species is the common mussel. Catch statistics for mussels and oysters do not distinguish between landings from cultured or wild stocks. Almost half of Denmark's total catch is from wild stocks. In Germany and The Netherlands the whole catch of mussels is obtained through cultivation. The landings of this species are listed under mariculture in section 3.6.

Mollusc seed fisheries, for redistribution of small mussels to more favourable plots, are a source for bivalve culture systems and can be complementary to natural spat falls which can sometimes fail. In the Wash, the mussel fishery collapsed at the end of the 1980s, when a period of intense exploitation was succeeded by a run of eight years without significant spat fall.

The cockle constitutes the second main catch of all mollusc species, especially in The Netherlands and in the United Kingdom. There are large fluctuations in cockle landings *(Figure 3.9)* due to natural cycles, including harsh winters. Landings of cockles in the Dutch Wadden Sea Conservation Area produced an average of 2 630 t/yr of meat between 1992 and 1996. Cockle fisheries are restricted or temporarily closed (e.g. in 1996) if stocks are low, and 26% of the intertidal area of The Netherlands is permanently closed for that reason and the number of licenses will not be increased. Cockle fisheries are not regulated outside the 12 mile zone.

In the Thames estuary cockle fishing has increased markedly since 1990, and landings have risen to between 10 000 and 25 000 t/yr, making it the largest cockle fishery

Figure 3.8 **Main mollusc fishing areas in the Greater North Sea. Source: redrawn from OSPAR 1998a.**



in Britain. In the Wash landings between 1970 and 1993 ranged from 1 000 – 10 000 t/yr, but since then they have declined due to a run of poor recruitment. In 1996–7 stocks were low and landings were restricted by seasonal and bed closures, but a modest recovery in stocks began in 1998–9. In Denmark and Germany cockle fishing is negligible.

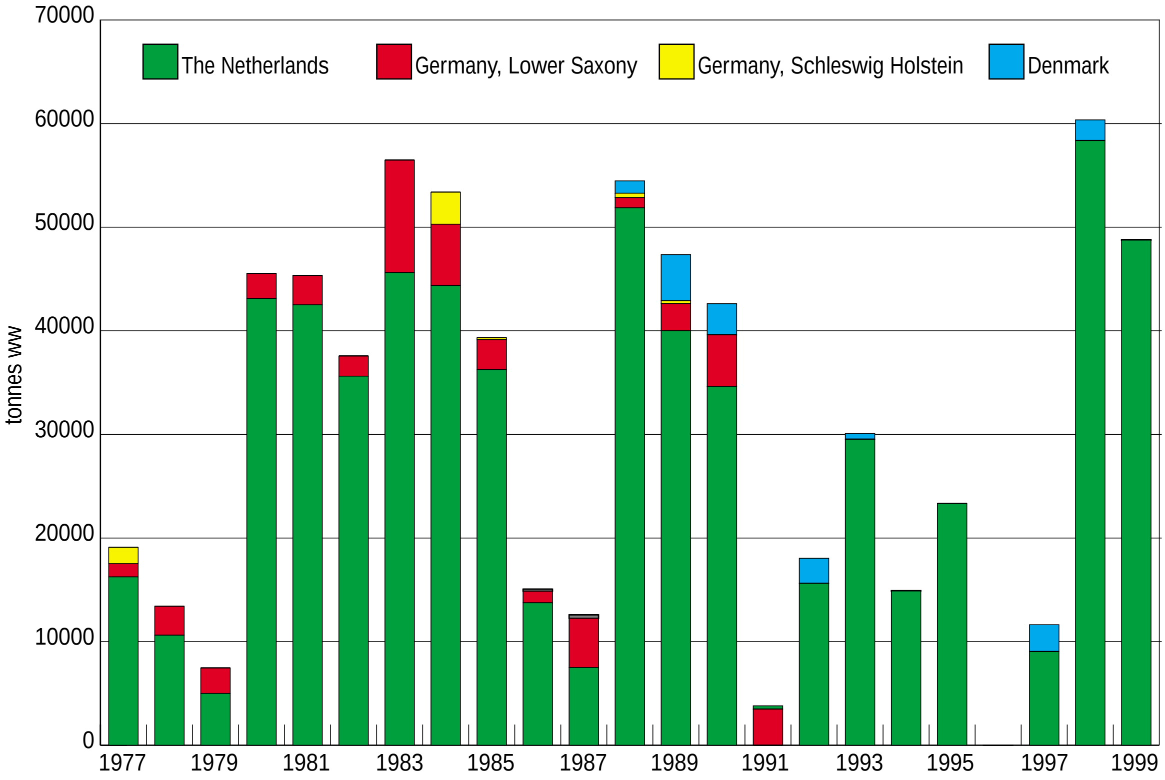
The fisheries for *Spisula* sp. started in the 1990s in Denmark and The Netherlands and have increased. Extremely low temperatures in the winter of 1995/96 led to mass mortality of *Spisula solida*. and it is not currently possible to fish for *Spisula* sp. in the area north of the Wadden Sea Islands (5NSC, 1997).

Scallops, mainly the great scallop (*Pecten maximus*), have been fished around Shetland and Orkney and in the Moray Firth with landings ranging up to a maximum of 4 527 t in 1996. Landings from the east of Scotland reached 1 900 t in 1995 before falling sharply to 678 t in 1996. In Norway, landings of scallops reached about 7 700 t (1994–5). Scallops are also fished in the Baie de Saint-Brieuc as well in the Channel where landings are rapidly increasing.

3.5.3 Seaweeds

Seaweeds, and in particular large brown algae such as the knotted wrack (*Ascophyllum nodosum*) and kelp

Figure 3.9 **Total landings of cockles (tonnes wet weight) in all regions of the Wadden Sea from 1977 to 1997. Source: De Jong *et al*. (1999).**



(*Laminaria hyperborea, L. digitata*), are occasionally harvested for alginate production, fertilisation and pharmaceutical use along some parts of the United Kingdom coast, along the French coast of the Channel and along the Norwegian west coast. The total amount of *L. hyperborea* harvested in the Norwegian part of the North Sea was on average 77 000 t/yr from 1995–7. In France in 1996, 57 000 t of kelp and 15 000 t of wrack (*Fucus* sp.) were harvested.

3.5.4 Fisheries management

Management of North Sea fisheries is regulated within the waters of EU Member States by the EU Common Fisheries Policy, and within Norwegian waters by national policy.

The most obvious tool in fisheries management is the TAC. International TACs, and national allocations within the TACs are agreed annually for the main fin-fish stocks of commercial importance but also for Norway lobster and prawn. TACs are agreed by the EU and Norway on recommendation by ICES. Other measures include, for example, the control of mesh size and net geometry, regulation of the minimum landing size and the by-catch limit and closures by season and area. Enforcement is undertaken nationally through the use of, for example, vessel lists and licences, log-book regulations and satellite monitoring. The EU Multi-annual Guidance Programme (MAGP) regulates the size of EU fleets.

Since 1998, advice, provided by the ICES Advisory Committee on Fishery Management (ACFM) and the EU Scientific, Technical & Economic Committee on Fisheries, strives towards consistency with a precautionary approach to fisheries management. In particular, ACFM has identified limit reference levels for mature stock biomass and fishing mortality and suggested precautionary reference levels. The methods are constantly being revised and improved in the internationally appointed working groups.

Data quality remains a concern. The accuracy of the annual TACs depends on the estimate of stock abundance. This is dependant on the availability of good quality catch data and information on stock abundance from surveys. Black fish or illegal landings can therefore undermine the system of management by TACs. Discards (see below) which are not monitored on an annual basis by most countries also affect the accuracy of stock assessments and TACs.

Discarding is the practice of throwing fish (and other marine organisms) back into the sea. In EU waters undersized fish, or fish over quota, have to be discarded. In contrast, in Norwegian waters no discarding of main commercial species is permitted. Most discarded fish die. Discarding of young flatfish is high on inshore nursery grounds, mixed roundfish discards are also high. Levels of discarding vary, however, by species, areas, fleets and seasons (Cotter *et al.*, 1999). ICES summarised 1998 statistics on discards in the North Sea (ICES, 1999b, see also chapter 5).

Specific measures recently introduced include:

- a revised regulation for the conservation of fishery resources through technical measures for the protection of juvenile marine organisms;
- an amendment to the control regulation requiring larger vessels to carry satellite monitoring equipment;
- new North Sea TACs for sandeels, anglerfish (*Lophius piscatorius*), megrim (*Lepidorhombus whiffiagonis*), dab (*Limanda limanda*) and flounder (*Platichthys flesus*), lemon sole (*Microstomus kitt*) and witch (*Glyptocephalus cynoglossus*), skates and rays (e.g. *Raja* sp., D*asyatis* sp.), turbot (*Psetta maxima*) and brill (*Scophthalmus rhombus*);
- the reduction of over-capacity of the EU fishing fleet by the ‘Multi-Annual Guidance Programme’ (MAGP).

The MAGP III (1992–6) aimed to reduce the capacity of fishing fleets by reducing tonnage and engine power. The level of reduction was dependant on the species caught and varied from no change up to a maximum of 20% in terms of 1991 fleet capacity.

In the ‘Annual Report to the Council and to the European Parliament on the results of the multi-annual guidance programmes for the fishing fleets at the end of 1997’, the European Commission noted that the implementation of the MAGP III had been successful in restructuring the European fleet. Between 1991 and 1996 the EU fleet tonnage and engine power was reduced by more than 10%. But it is noted that the degree to which programmes have been respected varies significantly between Member States. Two countries had failed to meet the objectives of MAGP III by the end of 1997, The Netherlands and, to a lesser degree, France. Other countries achieved greater reductions than MAGP III had required. The Danish and German fleets are now more than 20% below their target tonnage.

Although fleets have been reduced, the criticism from IMM 1997 was that ‘the reduction has been compensated for by an increase in efficiency, with the result that no reduction in fishing pressure has been achieved’. This may have happened through an increase of fishing days.

On account of this, the European Commission adopted MAGP IV for the period 1997 – 2001, with the aim of reducing fishing effort by 30% on stocks considered at risk of depletion and by 20% on over-fished stocks.

In 1998, Norway introduced a decommissioning scheme for coastal fishing vessels, similar to that for purse seiners in 1996. Regulations were aimed at prohibiting access of new trawlers to the shrimp fisheries.

Various national conservation measures have also been introduced. The UK introduced nursery areas for sea bass (*Dicentrarchus labrax*), designated ports of landing and restrictions to prevent fish from being discarded after they had been entered in a ship's log-book and placed in the hold. Improvements have also been made to the selectivity of *Nephrops* twin-rig trawls and in net geometry more generally. In Norwegian waters no discarding is permitted. Germany introduced a temporary closed area in 1996 to protect juvenile cod in the German Bight. A Danish action plan for reducing incidental by-catches of harbour porpoises includes measures such as the use of acoustic alarms, modifications to fishing equipment and regulation of certain types of fisheries.

Within EC legislation areas have been defined with limited fishing activities for the protection of juvenile fish, e.g. the plaice box in the south-eastern North Sea, and a box for Norway pout in the central North Sea.

Legislation related to shellfish fisheries has to ensure the proper management both of the sector and the ecosystem. However, many shellfish stocks e.g. *Spisula* sp., are localised and are therefore managed at national rather than EU level. Legislation for shellfisheries comprises TACs for Norway lobster and for northern prawn from the Skagerrak/Norwegian Deeps. Regulation EC/850/98 (EC, 1998), which came into force on 1 January 2000, specifies minimum sizes, mesh size bands and other gear restrictions. Minimum sizes are defined for Norway lobster, edible crab, velvet crab (*Liocarcinus puber*), crawfish (*Palinurus* spp.), whelk, and scallop. Other regulations may apply to the modernisation of fishery techniques, a reduction of fishing effort (either by absolute, or by selected restrictions for certain areas or periods), a minimum landing size, or a combination of all these.

3.6 Mariculture

Mariculture is undertaken in many of the North Sea states, but on a negligible scale in Belgium and Sweden. The Netherlands and Germany practise commercial shellfish farming only in the marine area. Mariculture may introduce to the environment nutrients (only 25% of the nutrients found in fish feed are converted into biomass (UBA, 1996)), organic matter, antifouling agents, biocides, antibiotics and other pharmaceuticals and colouring agents. Farmed individuals may escape, resulting in potential threats to native species.

3.6.1 Fish

Salmon (*Salmo salar*) is the main product of Norwegian and Scottish mariculture ***(Table 3.4)***. In Norway, between 1995 and 1996, the production of salmon increased by 32% to 120 000 t. In Orkney and Shetland in 1997 salmon production was 27 700 t, five times higher than in 1991.

The second main product in mariculture is the rainbow trout (*Onchorhynchus mykiss*). In Norway, the production of rainbow trout decreased by 28% in 1995. In Denmark, 10 land-based facilities for trout production are situated within in the North Sea catchment area. In Scotland in 1996 only 647 t was produced at six seawater sites, representing 14% of total Scottish rainbow trout production.

Other less important species cultivated in Norway are halibut (*Hippoglossus hippoglossus*), arctic char (*Salvelinus alpinus*), cod, turbot and eel (*Anguilla anguilla*). Sea trout (*Salmo trutta*), cod, halibut and turbot, sea bass and eels are being considered for production in the UK.

3.6.2 Shellfish

Farming of mollusc species includes blue mussels, oysters (*Ostrea edulis, Crassostrea gigas*) and scallops ***(Figure 3.8; Table 3.4)*** (OSPAR, 1998a).

Blue mussels are cultured in Denmark in the North Sea and in the Limfjord, in the Dutch and German Wadden Sea, in the Eastern Scheldt, along the coast of Brittany, in Norway, Sweden and the UK. Orkney and Shetland produce small but increasing quantities of mussels (107 t in 1997).

Oysters are cultured in the south-west of The Netherlands, in Norway, along the coasts of Normandy and Brittany, in Germany, on a small scale in Orkney and Shetland and in several estuaries on the south-east coast

Table 3.4 Mariculture production.

	Rainbow trout (t)	Salmon (t)	Blue mussel (t)	Oysters piece (p) or tonnes (t)	Scallops piece (p)	Clams (t)
Denmark (1996)	667	–	59 602	–	–	–
France	589	650	41 000	48 000 t	–	–
Germany (1996)	–	–	38 028	75 t	–	–
Netherlands	–	–	95 000	17 000 000 p	–	–
Norway (1996)*	12 000	120 000	180	530 000 p	90 000	–
United Kingdom (1996)	11 400	27 700	7 700	14 000 000 p	3 000	12
Sweden (1996)	< 100	–	1 800	–	–	–

* Preliminary data from 1996 published by Directorate of Fisheries 1997

of England.

Research has shown that it is technically feasible to rear native lobsters. In the UK, attempts are now being made to produce young lobsters for release into the sea, for restocking purposes.

To avoid the introduction of non-native species into Dutch coastal waters a new policy on the importation of shellfish and crustaceans was developed in 1996. By the year 2001 the introduction of native species from populations outside the North Sea area (boreal) into Dutch coastal waters will no longer be allowed.

3.7 Coastal engineering and land reclamation

Damming of rivers, for hydroelectric power generation for example, can cause drastic changes to the seasonal outflow of fresh water, with negative impacts on the productivity of coastal waters. Coastal land reclamation and dykeing change the physical environment which may affect spawning areas, biological diversity and wildlife.

3.7.1 Coastal defence

Coastal defence work and land reclamation is a common activity in the Greater North Sea, particularly around its shallow southern and eastern margins. Settlements along the Wadden Sea coast and on islands are especially vulnerable to storm surges and sea level changes. In view of a predicted sea level rise due to climatic change, countries revise their plans for coastal protection on a regular basis, for instance Germany does so every 10 – 15 years.

On sandy coasts, natural dunes play a major role in coastal protection. In several cases, dunes are protected against erosion by hard structures. However, this may lead to destruction of the natural beach through increased sediment deposition at some locations and enhanced erosion elsewhere. The present tendency is to use soft engineering approaches, such as artificial beach replenishment.

In 1996, The Netherlands processed 7.7 x 10^6 m^3 of sand for beach nourishment. With a predicted sea level rise of 60 cm in one century along the Dutch coast it is estimated that twice the present quantity of sand will be needed. In Germany, beach replenishment is carried out on the island of Sylt (1996: 1.03 x 10^6 m^3, 1997: 0.7 x 10^6 m^3 and 1998: 0.07 x 10^6 m^3) and at the islands of Langeoog, Norderney and Borkum. The major Danish beach nourishment activity is on a 110 km stretch along the west coast of Jutland (1996: 3.3 x 10^6 m^3). In the UK, on the Lincolnshire coast, beaches are recharged with sand.

Within the UK, future policies on risks of coastal flooding and erosion have been drafted in Norfolk County Council's *'Norfolk to 2006'*. Coastal protection schemes have been designed to include allowances for relative sea level rise up to 2030. These allowances, which also take account of long term geological tilt, vary between 4 mm and 6 mm/yr, depending on the location. An alternative option for the protection of beaches is to deploy (permanently submerged) offshore breakwaters parallel to the coast, as it is envisaged for example in Koksijde (Belgium).

3.7.2 Land reclamation

Most land reclamation projects have been carried out over previous centuries, and major activities have been conducted along the Dutch and German coasts (e.g. in the Wadden Sea and Rotterdam port area). Plans on the further expansion of the port of Rotterdam area through land reclamation are at an advanced state of development.

3.7.3 Power generation

Generation of electricity from tidal energy requires a minimum tidal amplitude of about 3 m. Due to the relatively low tidal excursion in the North Sea *(Figure 2.19)* opportunities for tidal power generation are very limited. The only tidal power station in the region has been operational since 1967 on the Rance estuary, near St Malo in Brittany, generating 240 MW (nominal).

At present, no power is generated from wave energy in the North Sea.

As wind is a cheap source of renewable energy there are intensive efforts to find convenient sites with sufficient wind energy and low population. The economic generation of electricity from wind, requires an average wind speed (at 10 m) greater than 5 – 6 m/s. The problems associated with wind power generators include the need for space, the unsightliness of the turbines, the direct mortality of birds caused by rotating blades and the noise impact especially on birds. The construction of wind turbines in the Wadden Sea Conservation Area is prohibited by national legislation, and is only permitted outside the Conservation Area if ecological and landscape characteristics are not negatively affected.

Plans are being developed for wind parks off shore. Legislation for offshore wind parks is under development in Belgium. In Denmark, current plans for offshore wind power generation in Region II include two large scale parks, one situated off the Danish west coast and one off the island of Laesø in the Kattegat. In The Netherlands, a plan for an off shore wind park, with 100 wind turbines generating 100 MW, is under discussion. Offshore wind power generation is also being seriously considered at a number of locations off the English coast.

3.8 Sand and gravel extraction

The marine aggregate extraction industry is well established and growing in a number of countries in Region II, providing up to 15% of some nation's demands for sand and gravel (ICES, 1992). Most commercially workable deposits of sand and gravel occur in the shallower regions of the North Sea. In 1996, about 40 x 10^6 m^3 were extracted from the sea *(Table 3.5)*, compared to 34 x 10^6 m^3 in 1989. The exploitation of sand and gravel often has negative impacts on fishing interests, the benthic flora and fauna, coastal protection and on the physical properties of the seabed. The exploitation of shallow banks close to the shore increases the potential for coastal erosion by enhancing wave activity and, therefore, careful assessment of the potential impact is needed. Most countries report increasing concerns about the extraction of aggregates (ICES, 1997). The ICES Code of Practice for the Commercial Extraction of Marine Sediments provides step-by-step advice on how marine dredging should be conducted in order to minimise conflicts with other users of the sea and to optimise the use of marine resources.

Exploitation of calcium carbonate shell aggregate is licensed in the Dutch part of the Wadden Sea and in areas outside the tidal inlets, with annual extractions of 140 000 m^3 in the Wadden Sea and 60 000 m^3 in the areas outside the tidal inlets (ICES, 1997). In 1996, off the French coast, 562 000 t of calcareous material (shelly sands and *Lithothamnion* banks) were extracted. In 1996, deposits of calcareous algae (maerl) were exploited in the Orkneys (4 000 m^3/yr licensed).

Table 3.5 Quantities of sand and gravel (m^3) taken from marine sources in 1996 and average for 1992–7. Source of data: ICES (1997), OSPAR (1998b).

Country	1996	Average per year (1992–7)
Belgium	1 444 629	1 833 333
Denmark	3 700 000	5 083 333
France *	590 000	2 200 000
Germany	1 100 000	
Netherlands	23 200 000	17 366 666
Norway **	86 111	118 333
Sweden #	0	5 917
United Kingdom **	9 500 000	13 600 000
TOTAL	39 620 740	

1996 data from ICES (1997).

* Data from France.

** m^3 estimated from tonnes.

\# Since 1992 no sand and gravel extraction occurs in the Swedish part of the Kattegat and Skagerrak area due to environmental reasons.

3.9 Dredging, dumping and discharges

Dumping of waste or other matter is prohibited by the OSPAR Convention, with the exception of dredged material, waste from fish processing, inert material of natural origin and, until the end of 2004, vessels or aircraft. The annual OSPAR Reports on Dumping of Wastes at Sea present an overview of the number of permits issued for most of the dredged materials concerned.

A wider range of material, including sewage sludge and industrial waste has been disposed of in the past. The dumping of industrial wastes was phased out in 1993 when the last few UK licences for disposal at sea of liquid industrial waste and fly ash expired. Incineration of liquid industrial waste on special incinerator vessels in the North Sea was terminated in 1989. The dumping of waste from the production of titanium dioxide was terminated in 1989. Discharges from the titanium dioxide industry are permitted under Council Directive 92/112/EEC (EC, 1992) and are mainly confined to French and UK estuarine waters (Seine, Humber and Tees).

3.9.1 Dredged material

Dredged material dumped at sea consists primarily of material removed to keep navigation channels clear or removed in the course of coastal construction engineering projects. Dredged material may be used e.g. for beach nourishment, land reclamation or for salt marsh preservation.

A total of 88 x 10^6 t (dw; from internal and external waters) were dumped in the Greater North Sea in 1996 *(Figure 3.10, Table 3.6)*. In comparison with previous years, no trend is observed. The need for maintenance dredging is determined by natural variation in transport and sedimentation of fluvial and marine sediments, and is not expected to increase in the long term. Changes are anticipated in the shipping fleet with the use of larger draught ships, which will mean a significant increase in the amount of capital dredging (in the short term) for some ports. This creates a problem of volume rather than of contamination (deeper layers of sediment are usually from pre-industrial times).

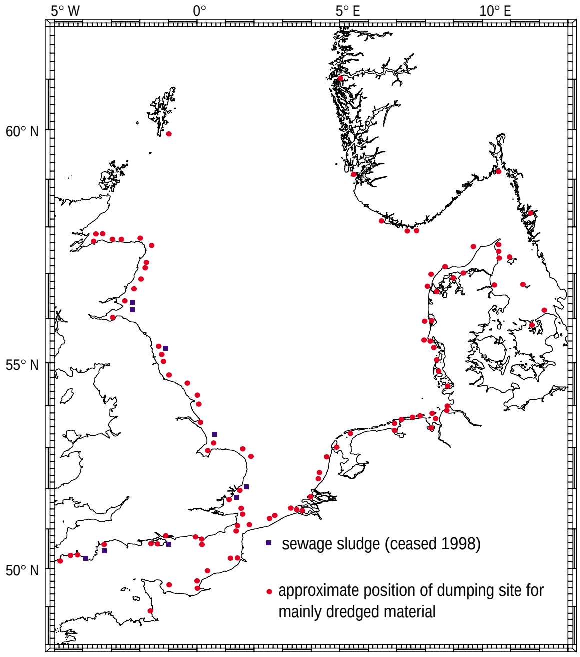
3.9.2 Sewage sludge

The dumping of sewage sludge has been banned under the OSPAR Convention since 1 January 1999. Only two countries dumped sewage sludge in the North Sea, and Germany ceased this practice in 1981 and the UK in 1998. Quantities dumped by the UK in 1996 amounted to about 5.9 x 10^6 t ww (or 142 000 t dw).

3.9.3 Inert materials of natural origin

In 1994, although no inert material was dumped at sea,

Figure 3.10 **Dumping areas in the Greater North Sea in 1996 (1994 for France). Source of data: OSPAR (1997a and 1999a).**



300 000 t were deposited from land onto the foreshore: 230 000 t by Norway and 70 000 t by the UK. Overall the disposal of such material has decreased considerably, as the amount for 1994 was less than 10% of that for 1990.

3.9.4 Ships and bulky wastes (iron scrap)

In 1996, Norway dumped 6 vessels in the North Sea, mainly wooden fishing vessels, but also some iron vessels. Chemicals and loose parts were removed before dumping. Dumping of iron/steel hulled vessels is now forbidden, and dumping of all other ships will be forbidden after 2004.

Table 3.6 Dredged material (in tonnes dry weight) dumped in 1996. Source: OSPAR (1999a) and national data(*).

Country	
Belgium	29 264 498
Denmark *	1 536 000
France *	13 360 000
Germany	19 123 000
Netherlands	8 016 381
Norway	42 196
Sweden	3 308 608
United Kingdom	14 130 219
(United Kingdom dumped sewage sludge)	(142 045)
Total dredged material dumped	88 780 902

In consideration of an initiative of the 4th International Conference on the Protection of the North Sea (4NSC, 1995), the 1998 Ministerial Meeting of the OSPAR Commission adopted Decision 98/3 on the Disposal of Disused Offshore Installations which prohibits dumping or leaving wholly or partly in place within the marine area, disused offshore installations. Subject to assessment and consultation under agreed procedures, derogations are possible for the footings of steel installations weighing more than 10 000 t and for concrete installations.

3.9.5 Discharges from offshore installations

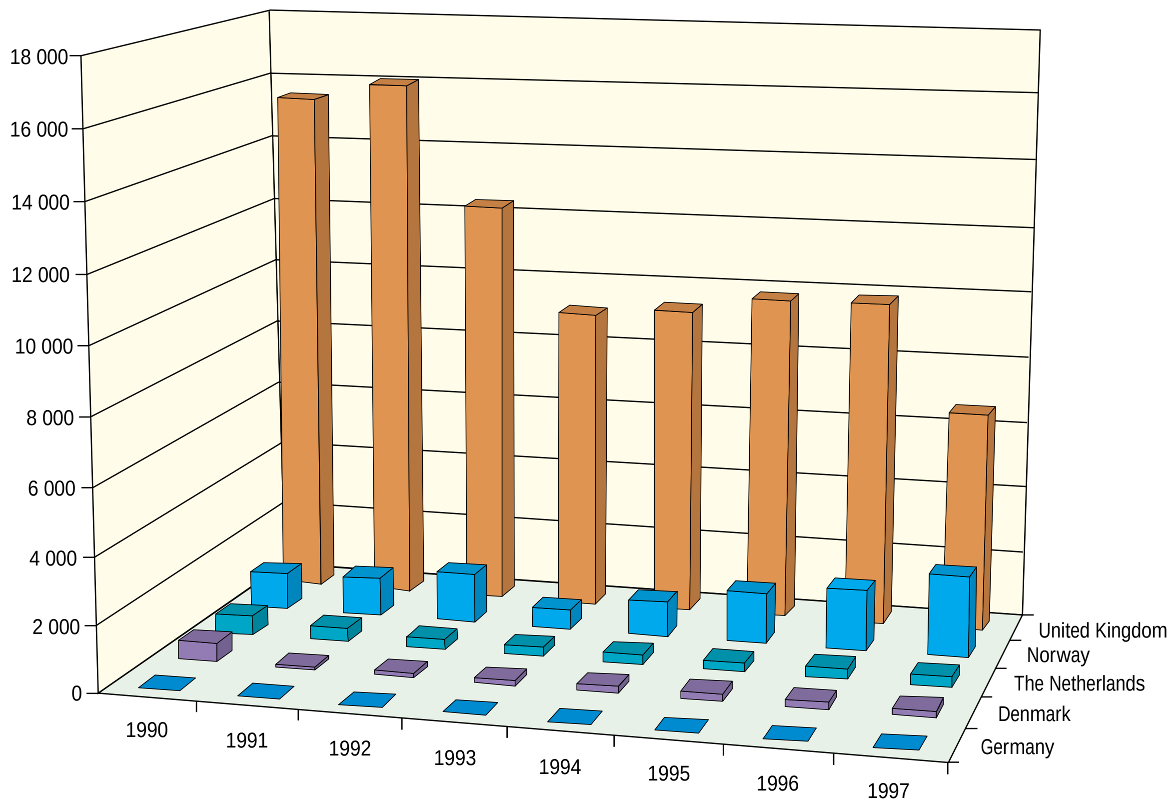
Offshore oil and gas installations are significant sources of hydrocarbons. Variations in annual discharges of oil from offshore installations in the OSPAR Convention area are shown in *Figure 3.11* (not taking into account synthetic muds which fall into a different category and, for those which degrade poorly, should be phased out by the end of 2000).

Heavy metals, PAHs and production chemicals are discharged via produced water *(Table 4.17)* which is only treated to remove oil. These inputs have increased substantially (OSPAR, 1999) which is attributed to the increasing age of the fields. The amount of discharged produced water can be reduced by methods such as re-injection into the reservoir or by downhole separation, which is largely experimental at present. Operational discharges, comprising produced water and cuttings are discussed in Chapter 4, as are any chemicals associated with those discharges. All waste from offshore installations is returned to land.

OSPAR adopted on a trial basis Decision 96/3 on a Harmonised Mandatory Control System for the Use and Reduction of the Discharge of Offshore Chemicals. It aims to reduce the impact from hazardous chemicals used by the offshore industry. Lists of compounds that may or may not be used are compiled on the basis of (ecotoxicological) risk assessment models including, for example, the ‘Chemical Hazard Assessment and Risk Management Model’ (CHARM). Another decision (1997) provides a list of substances or preparations (composed of two or more substances) which shall be subject to strong regulatory control. So far no substances have been identified which must not be discharged.

When drilling bore holes during the exploration phase, use was often made of oil- and water-based muds. Contaminated cuttings were regularly discharged overboard. At the 4th NSC, ministers invited OSPAR to ban discharges of oil contaminated cuttings by 1997. In exceptional cases the discharge of oil contaminated cuttings could be allowed only when essential for safety or geological reasons, and if consistent with PARCOM Decision 92/2.

Figure 3.11 **Total discharges of oil (in tonnes) from offshore installations to the OSPAR Convention area. Source: OSPAR (1999b).**



3.9.6 Litter

Despite pertinent laws and regulations, litter is still a considerable problem for the marine environment and the coastal communities in Region II. Potential sources of litter are mainly related to waste generated by shipping (fishing, commercial) on the North Sea and touristic and recreational activities *(Table 3.7)*. The offshore industry is not considered to be a source of waste pollution at sea thanks to improvements in its waste management practice. Some waste may be depositied illegally and some by accident. Litter may also be transported into the sea by winds, currents and rivers. It has been estimated that the North Sea has to cope with about 70 000 m^3 of litter per year, and some 6.6 million pieces (or 8 600 t) were estimated to be present in the Dutch sector alone.

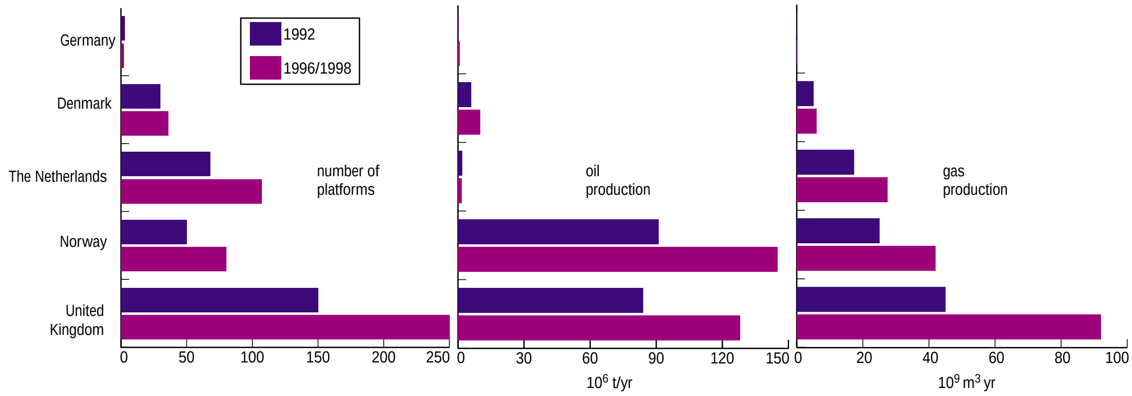
Non-degradable plastics may constitute 95% of the total amount of litter in many areas of the OSPAR region. Litter, including drifting fishing nets and ropes, may entangle and drown mammals and seabirds. It has also been found to carry a variety of epiphytic organisms to sea areas that these organisms would not normally reach. Economically, the recreation sector is likely to be most affected by litter. Remains of plastic nets can easily get caught in ship's propellers.

The North Sea (1991) and the Baltic Sea (1988) have both been designated as MARPOL Special Areas (Annex V) where the dumping of garbage and litter from ships (e.g. household waste, cargo waste, wire straps, covering material, fishing equipment) is prohibited. Dumping of waste is also prohibited under the OSPAR Convention. So far, however, there is no indication of any improvement with regard to litter.

3.10 Oil and gas industry

The offshore oil and gas industry has become a major economic activity in the North Sea since the late 1960s. Between 1990–92 and 1996–98, the number of platforms increased from 300 to 475, and oil production almost doubled *(Table 3.8; Figure 3.12)*. The major oil developments have been in the northern parts of the North Sea in the United Kingdom and Norwegian sectors *(Figure 3.13)*. Gas deposits are exploited mainly in the

Figure 3.12 **Comparison of offshore activities in 1990–92 (North Sea Task Force, 1993) with those in 1996–98.**



Data for Denmark, Germany and The Netherlands are from 1996. Data for the United Kingdom are from 1997. Data for Norway are from 1998.

Table 3.7 Waste (m^3) generated yearly in the North Sea region by different sectors, whereof a part may end up as litter. Source: OSPAR (1997b).

Sector	
Ferry traffic	290 000
Fishing vessels	100 000
Offshore installations †	90 000
Merchant shipping	60 000
Pleasure crafts	40 000
Recreation, tourism	20 000
TOTAL	600 000

† Waste collection, return to land and disposal onshore is strictly controlled in this sector. Consequently there is a low risk that waste from offshore installations contributes to marine litter.

Table 3.8 Gas and oil production by countries bordering the North Sea in 1996–8.

Country †	Number of platforms in production	Gas production (10^9 m^3/y)	Oil production (10^6 t/y)
Denmark (1996)	36	6	10
Germany (1996)	2	0.3	0.5
Netherlands (1996)	107	27.4	1.8
Norway (1998)	80	42	145
United Kingdom (1997)	250	92	128
TOTAL	475	167.7	285.3

† Belgium, France and Sweden do not have gas or oil production.

shallower southern regions in the United Kingdom, Dutch, and Danish sectors, as well as in Norwegian waters. There are several gas and oil production platforms in the Wadden Sea, with further exploration being subject to tight controls. Discharges are described in section 3.9.5.

The total length of pipelines has increased as, for example, pipelines connecting Norway and France (840 km) and Belgium to UK (240 km involving the dredging of 4 x 10^6 m^3 sand) were completed in 1997. In 1998, 9 670 km (estimated from 1998 sea charts) of rigid and flexible oil and gas pipelines formed a network of arteries between offshore petroleum production sites and terminals on land. These pipes represent approximately 1.7 and 2.2 x 10^6 t of steel and concrete, respectively. Furthermore, approximately 5 100 t of tar and 62 000 t of asphalt cover the pipe joints, and about 10 000 t of aluminium and 6 500 t of zinc anodes are fitted as electro-chemical protection against corrosion. The lifetime of individual pipelines is estimated to be from 20 to 50 years (Jacobsen *et al.* 1998).

3.11 Shipping

3.11.1 Traffic and cargo

The North Sea contains some of the busiest shipping routes in the world. In 1996 about 270 000 ships entered the main 50 ports in the North Sea and Channel area. Daily, more than 400 ships pass through and 600 ships cross (including 200 ferries) the Strait of Dover. In 1996 there were 37 055 shipping movements transporting 48 million tonnes of cargo between the North Sea and the Baltic via the Kiel Canal.

Most of Europe's largest ports are situated on North Sea coasts and rivers, namely Hamburg, Bremen, Amsterdam, Rotterdam, Antwerp, Le Havre, and London (*Figures 3.14* and *3.15*), with Rotterdam/Europoort being the most important. Container transfer in the main ports increased by 120% in the last ten years (*Table 3.9* and *Figure 3.16*). Approximately half the shipping activity in the Greater North Sea consists of ferries and roll-on/roll-off vessels on fixed routes.

Shipping can have a negative impact on the marine

Figure 3.13 **Oil and gas industry in the North Sea in 1996. Source: modified from Schöneich (1998).**

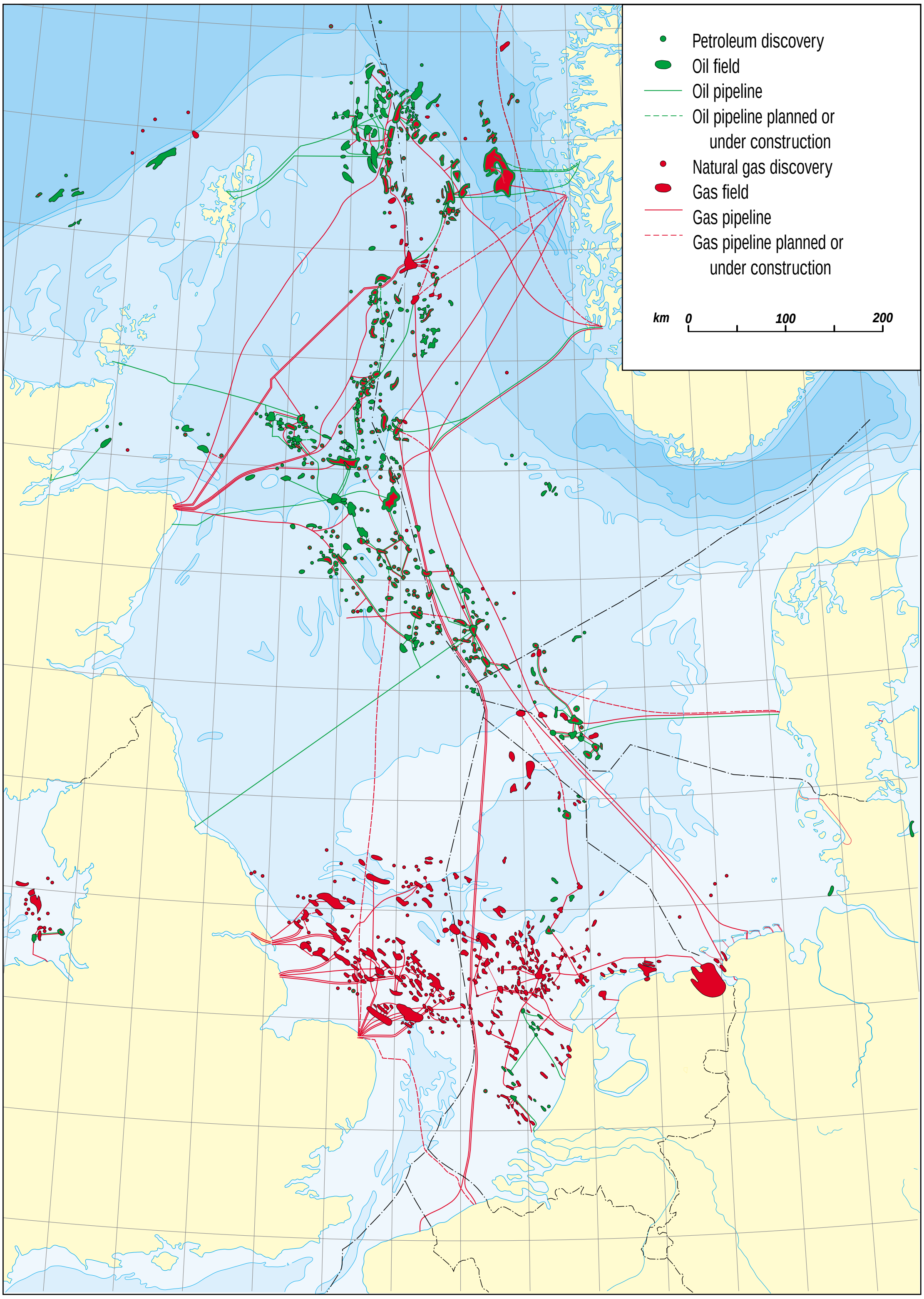


Figure 3.14 **Shipping in the Greater North Sea, showing total cargo shipments (10^6 t/yr) in the main ports in 1997 and international shipping traffic measures. Source of data: Port of Rotterdam (1999) and Department of the Environment, Transport and the Regions (UK) (1997).**

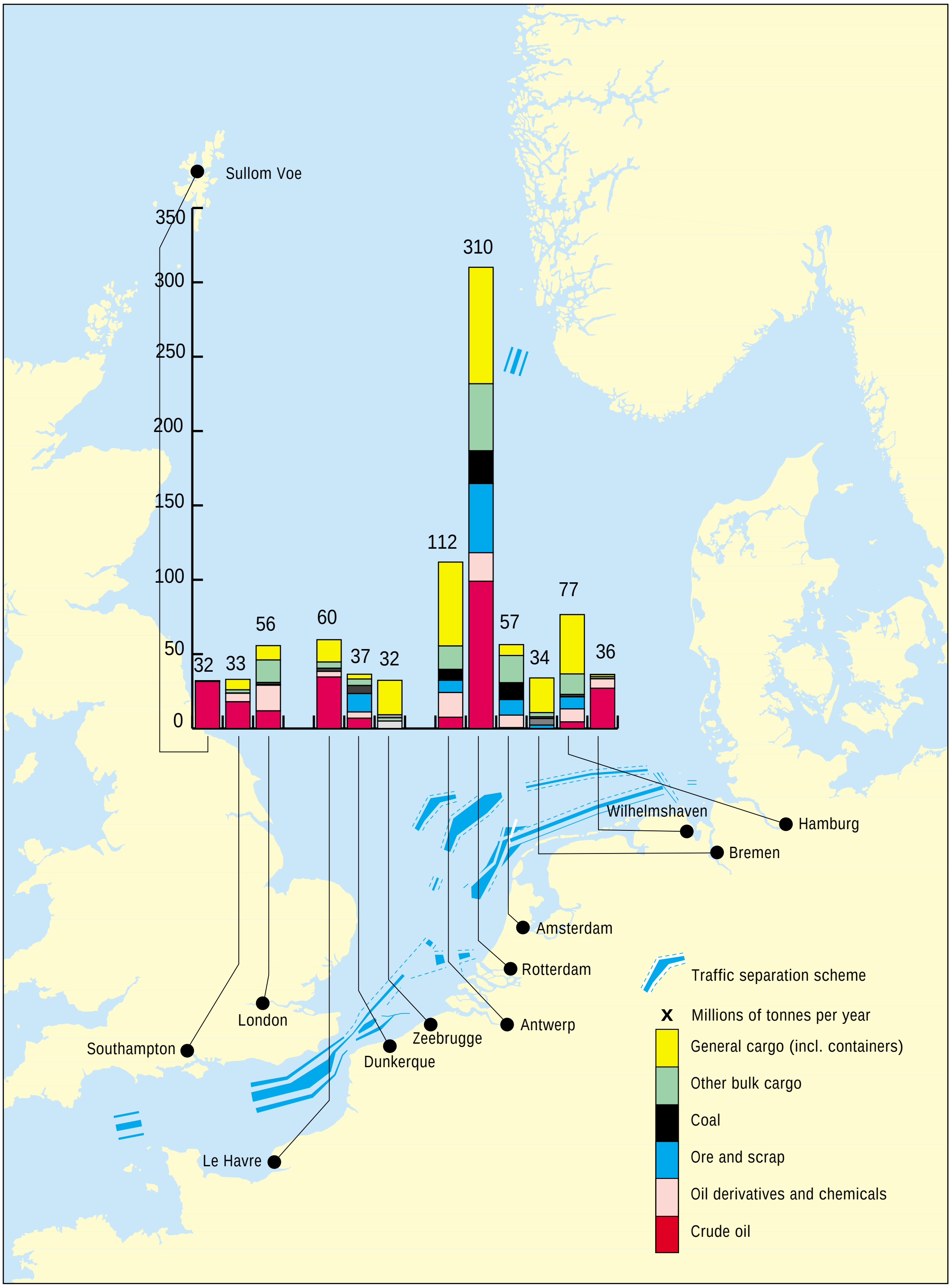
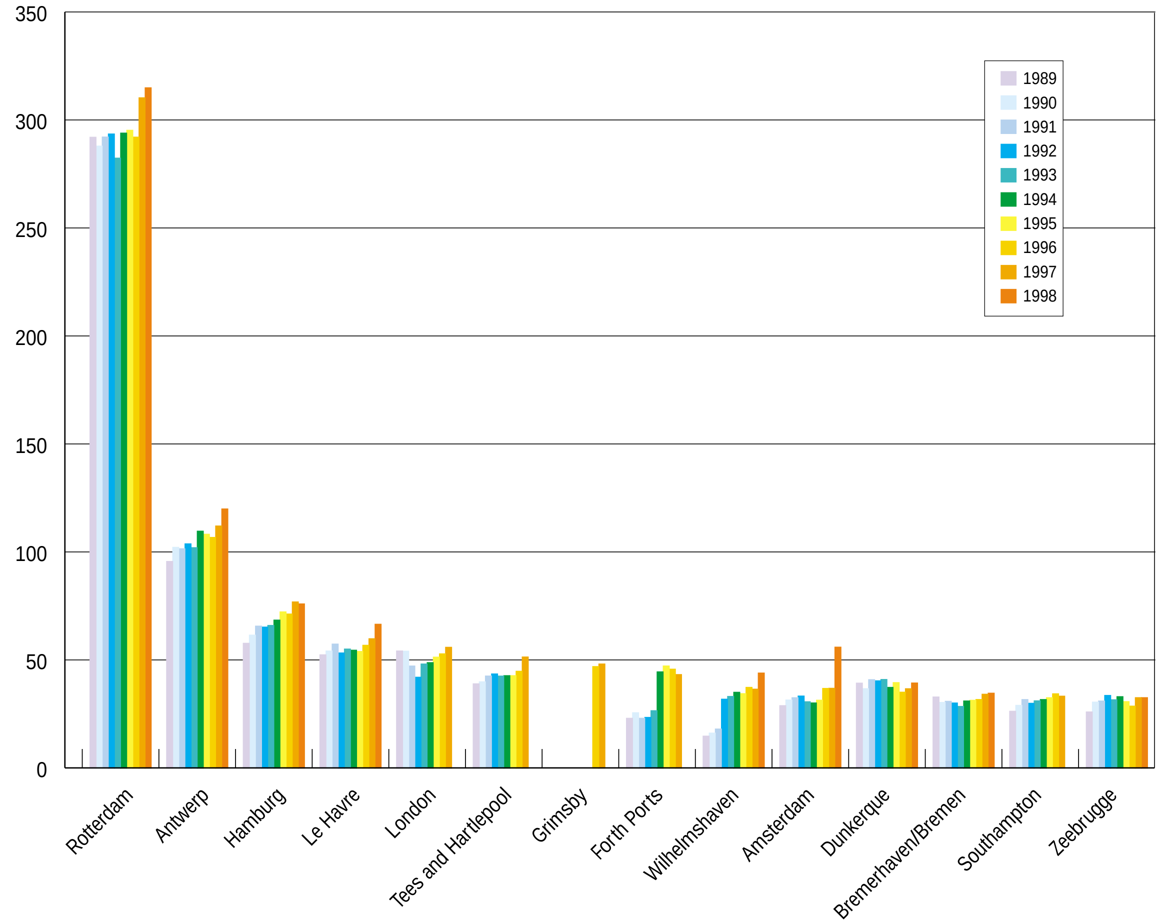


Figure 3.15 **Development in shipments (10^6 t) in North Sea ports from 1984 to 1998.**



environment due to discharges of oil and wastes, cleaning and venting tanks, air pollution, loss of cargoes containing harmful substances (50% of goods carried at sea can be described as dangerous), discharges of ships' ballast water which may contain non-indigenous species, and the use of anti-fouling paints containing biocides.

As from 1 August 1999, the North Sea, the Seas around Ireland and their approaches have been established under the name North West European waters as a Special Area under MARPOL Annex I (oil). Within the IMO, a mechanism for a general ban on the use of organotin compounds in anti-fouling paints has been agreed. The target is to prohibit their application from 2003 and to require the removal of TBT from ships' hulls by the year 2008. Given the serious effects of TBT on snail and bivalve populations, effective implementation of this measure is required. Within the EC, controls on other TBT applications have been increased with the revision of Directive 76/769/EEC. The Marine Environmental Protection Committee (MEPC) plans to develop a global legally-binding instrument to address the harmful effects of anti-fouling systems used on ships. Within the IMO framework, activities are also ongoing to reduce air pollution by emissions.

3.11.2 Accidents

In the North Sea in 1993 a serious pollution incident occurred when the 'Braer' ran aground in Shetland releasing 84 700 t of crude oil and 1 600 t of bunker-C oil. In the Greater North Sea, eleven accidents occurred in 1994 and six accidents occurred in 1995 where pollution of the seawater was recorded (world wide 101 in 1994 and 86 in 1995) (Quell and Klimsa, 1997). In 1996, two major cases of fire and one of grounding were reported in the North Sea or adjacent waters (Hooke, 1997).

In 1998, the ship 'Pallas', under a Bahamas flag and carrying a shipment of timber, caught fire off the coast of Jutland and finally ran aground near the German island of Amrum, spilling an estimated 244 m^3 of heavy fuel oil causing the death of about 16 000 overwintering birds.

Lost cargo can cause harm to the environment. In 1994, The Netherlands registered lost containers with various types of cargo on five occasions. In one case the 'Sherbro' lost

Table 3.9 **Development of market shares in container t ransfer. Source of data: Wirtschaftsbehörde Hamburg (1998).**

	1985		1990		1997		
	Quantity (1000 TEU)	Market share (%)	Quantity (1000 TEU)	Market share (%)	Quantity (1000 TEU)	Market share (%)	Increase in quantity 1985-97 (%)
Rotterdam	2 655	43.9	3 666	43.7	5 340	40	+ 101
Hamburg	1 159	19.1	1 969	23.5	3 337	25	+ 188
Antwerp	1 243	20.5	1 549	18.5	2 969	22.2	+ 139
Bremen ports	998	16.5	1 198	14.3	1 705	12.8	+ 71
TOTAL	6 055		8 382		13 351		+ 120

TEU = 20 ft container equivalent unit

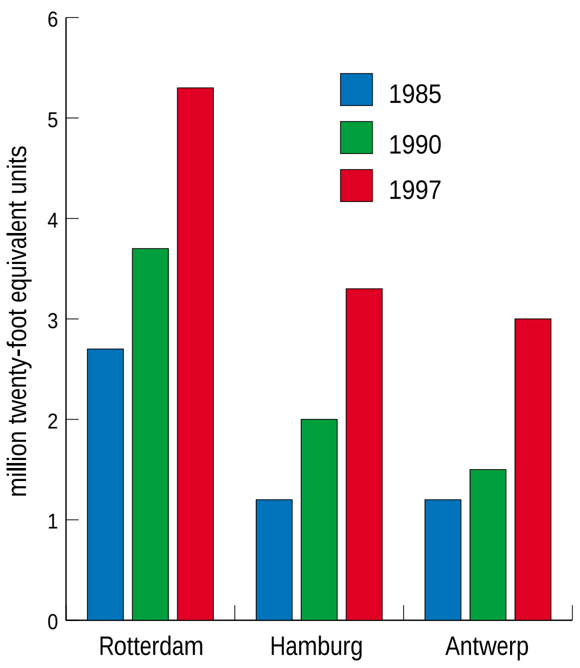
88 containers, 5 of which contained the pesticides ‘Apron Plus’ and ‘Ridomil Plus’, and ‘Apron Plus’ packages from this accident washed up on the Dutch and German coasts. In another case the coast of a Dutch Wadden Sea island was polluted by lumps of elemental phosphorus.

To reduce the risk of accidents, the IMO has introduced shipping corridors in several regions of the North Sea *(Figure 3.14)*.

3.12 Coastal industries

Industries of various types (e.g. metal and metal-processing industry, chemicals industry, shipbuilding) are located along the coasts of the North Sea.

Figure 3.16 **Development in container transfer in Rotterdam, Hamburg and Antwerp 1985–97. Source: Wirtschaftsbehörde Hamburg (1998).**



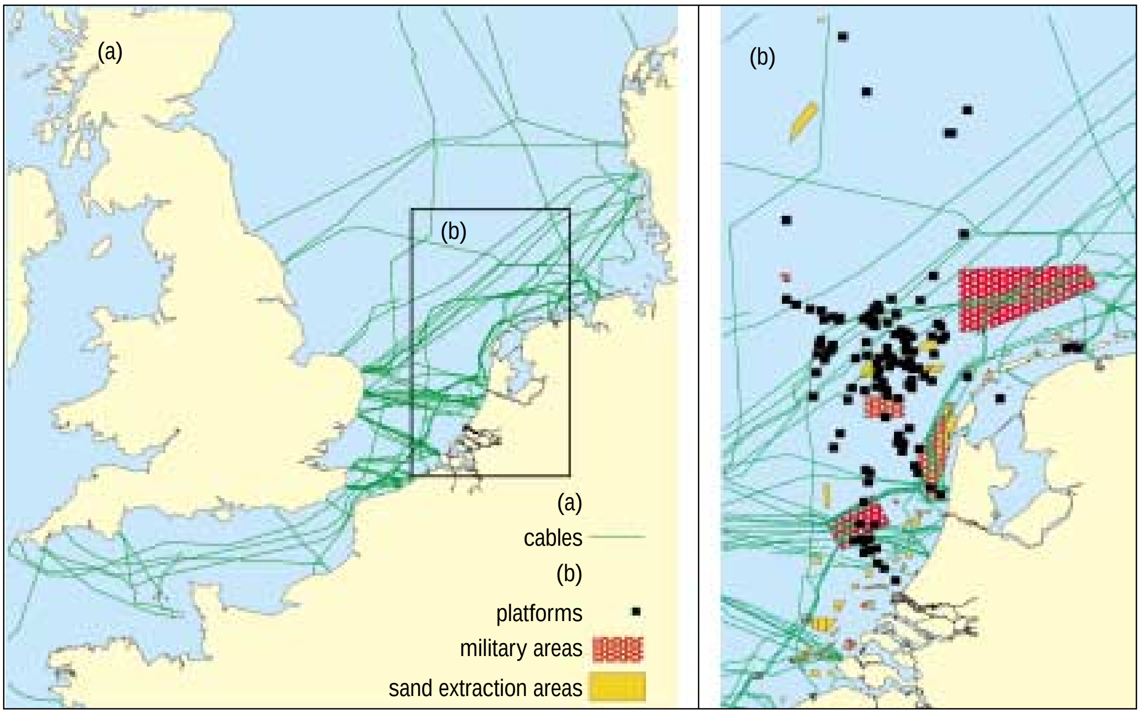
The most industrialised coastal area in Norway is the Frierfjord area. Along the south and west coast most industries are situated in the innermost part of the fjords, often in connection with larger cities (Oslo, Bergen), or at locations where hydroelectric power is generated (smelting plants). Some oil refineries are located in the coastal zones. In Denmark, industrial production is on the east coast of Jutland, and near Esbjerg. German coastal industries are concentrated near the banks of the rivers Elbe, Weser, Ems and Jade. In The Netherlands, industries are situated in the Scheldt estuary, in the estuary of the Rhine/Meuse (Rotterdam area), and near Amsterdam and Ijmuiden. The Belgian coastal industry is mainly situated in the Antwerp area, close to the Scheldt estuary. On the French coast, various industrial developments are focused on the Calais-Dunkerque coast and the Seine estuary. The main UK industries on the coasts of Region II are found in the estuaries of the rivers Thames, Tyne and Tees, near Southampton and in the Firth of Forth.

missions to air or discharges to water or indirectly by effects on land or soil. Industry uses water in large quantities for cooling, rinsing and cleaning.

Some nuclear power plants and the French reprocessing plant can be considered as coastal industries discharging heat and radioactive substances into the marine environment. OSPAR reports show that the discharges from most facilities are much lower than those permitted. In their Statement at the Ministerial Meeting in 1998 (Sintra, Portugal), OSPAR Ministers agreed to ensure that discharges, emissions and losses of radioactive substances were reduced by the year 2020 to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, were close to zero.

Many data and energy cables and pipelines are submerged in the North Sea sediment (*Figures 3.13* and *3.17*). Over 5 000 km have been dredged for this purpose. This may become a problem for some user functions and groups, such as beam trawl-fisheries and sand, gravel and shell extraction. Within their territorial waters countries can demand that cables and pipelines are removed when no longer in use.

Figure 3.17 **Cables, military training areas and sand extraction areas in the North Sea. Source of data: Rijkswaterstaat North Sea Directorate (Netherlands).**



3.13 Military activities

Military uses of the sea in peacetime constitute a small part of the sea-borne and coastal activities around the Greater North Sea. Activities include fishery protection patrols by the respective navies, and NATO exercises.

There are extensive British Royal Navy exercise areas in the Greater North Sea, mainly concentrated off the south coast of the UK. There are also exercise areas off the eastern coast of England and around the Firth of Forth.

Dumping of munitions at sea, including chemical weapons, took place after World War I, e.g. at the location 'Paardenmarkt' off the Belgian coast, and after World War II. Before 1947, the Allies sunk 34 ships in the Skagerrak containing roughly 150 000 t of chemical weapons (Duursma, 1999). The chemicals involved included mustard gas, tabun, chloroacetophenone and different arsenic containing compounds. Other ammunition dumpsites are also located in the Channel and off the southeast coast of the UK.

3.14 Land based activities

3.14.1 Non-direct discharges

Land-based activities such as industry, households, traffic and agriculture may have an impact on the ecosystem of the Greater North Sea via riverine or atmospheric inputs of contaminants. Quantification has focused on the overall input of substances to the marine environment, and for substances other than nutrients only limited attention has been given to the contributions from different sources (see also Chapter 4). Substances of concern are nutrients, which may lead to eutrophication, and hazardous substances which could pose a risk to marine organisms and, via food from the sea, to human health.

At the International Conferences on the Protection of the North Sea, commitments were made to reduce inputs of hazardous substances and nutrients into the North Sea by 50% between 1985 and 1995 and also to reduce by 70% inputs of dioxins, mercury, cadmium and lead.

Reductions in mercury discharges have been achieved by measures taken in the chlor-alkali industry, by mercury replacement in certain products and by reducing discharges from dentistry. For cadmium reductions have been achieved by minimising discharges from the (non)-ferrous metals and fertiliser industries, and through the substitution of cadmium by less harmful elements. Efficient flue gas treatment has reduced atmospheric emissions of cadmium, mercury and dioxins. Lead emissions from petrol have declined markedly.

Reduction in the inputs of phosphorus and limited reductions in the inputs of nitrogen were achieved through improvements in sewage treatment (see below); and by reductions in ammonia volatilisation, in leaching of nitrate, in losses of phosphorus, and in farm waste discharges.

Little success has been reported in reducing inputs from diffuse sources, i.e. erosion and leaching of arable land (fertilisers), atmospheric deposition (nitrogen), run-off from roads (e.g. wear of tyres) and building materials.

Consequently, the North Sea States considered further action to achieve the reduction targets by, for example, enhanced substitution of hazardous metals in various applications, replacement of products and by more stringent controls of industries discharging wastes.

To achieve a decline in atmospheric emissions, measures such as improvements in flue-gas cleaning at waste incinerators and coal-fired power stations and the introduction of best available technology for the metallurgical industry were adopted.

3.14.2 Domestic sewage

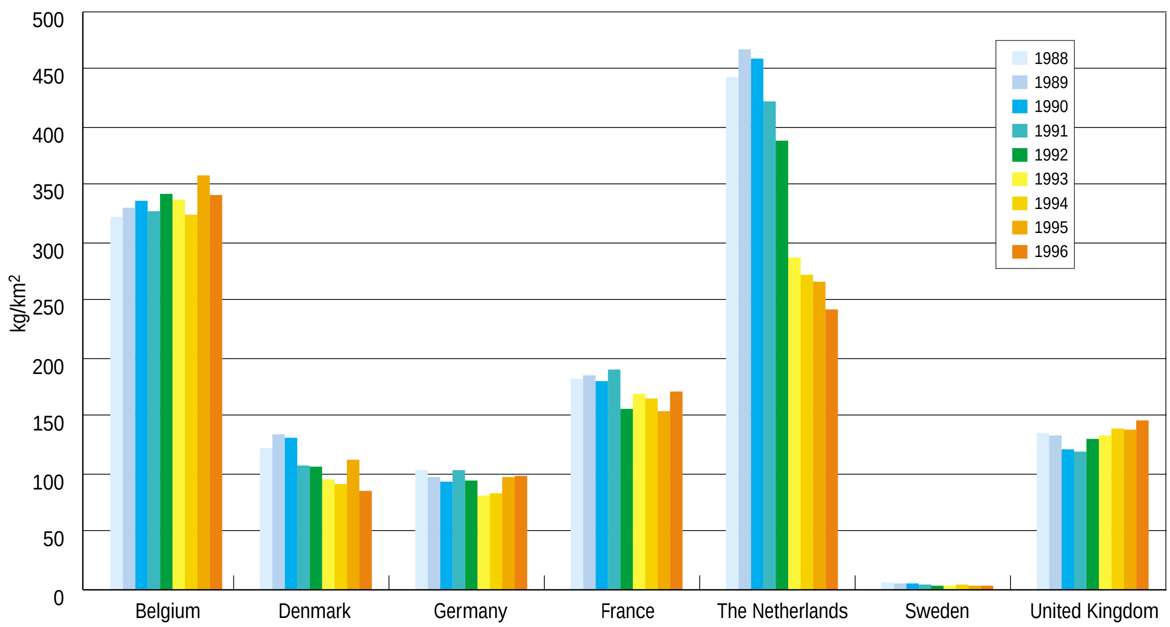
Considerable effort has been made to collect urban and industrial waste waters and apply appropriate levels of treatment. Nevertheless, even where households and industries are served by tertiary treatment systems, exceptional rainfall or tourism during the summer can reduce the efficiency of these systems. Measures relating to the reduction of nutrient inputs were adopted by the Paris Commission in 1998 and 1999 (PARCOM Recommendations 88/2 and 89/4). The EC Urban Waste Water Treatment Directive (EC, 1991) regulates the required level of treatment of waste water (i.e. in general biological treatment). The deadline for implementing this Directive is 31 December 1998 to 31 December 2005, depending on the size of the population. In 1995 the portion of the population connected to sewerage treatment in different countries ranged from 80 – 98% (OSPAR, 1995).

3.15 Agriculture

Highly productive agricultural systems in Western Europe fall into two broad categories. Firstly, there are areas of intensive field-crop farming, dominated by large holdings concentrated in eastern England, northern Germany and much of The Netherlands. Secondly, there are areas of very intensive agriculture specialising in animal production and/or fruit and vegetable farming found in the coastal and southern areas of western Denmark, parts of Germany, The Netherlands, northern Belgium, and northern Brittany. Agricultural land accounts for more than 42% of the total land area in Europe, although the proportion varies between less than 10% and more than 70%.

There are considerable environmental impacts associated with agricultural activities and the main types of pollution are from nitrates, ammonia, methane, pesticides and run-off of silage and slurry. Trends in the use of pesticides in countries bordering the North Sea are shown in *Figure 3.18*. Emission of nitrates and phosphates can lead to eutrophication of coastal waters.

Figure 3.18 **Trends in the use of pesticides in agriculture from North Sea countries from 1988 to 1996 related to the total surface of the country. Source of data: Eurostat (1998).**



Reduction of nutrient inputs from agriculture was addressed by PARCOM Recommendation 92/7. Agriculture also contributes emissions to the atmosphere (including, in particular, ammonia and methane) (European Environment Agency, 1995).

3.16 Regulatory measures and future developments

The environmental policy framework for the North Sea is developed through the International Conferences on the Protection of the North Sea, under the OSPAR Convention, in the framework of the European Union, by the Trilateral Governmental Wadden Sea Conferences, under the Bonn Agreement and, indirectly, under the London Convention and in the framework of the IMO. It takes into account the Rio Declaration and policies developed under the Convention on the Protection of the Marine Environment of the Baltic Sea (Helsinki Convention 1997/1992). Additionally there is co-operation in the framework of international river conventions, such as for the Elbe, Rhine, Scheldt and Meuse.

The four ministerial NSCs held since 1984 have resulted in political commitments to implement certain measures at a national or OSPAR level, or within the EU. Important agreements were to adopt the precautionary principle and to reduce inputs of hazardous substances and nutrients.

The OSPAR Convention, which was opened for signature in 1992 and came into force in March 1998, served to merge and modernise its predecessors the Oslo Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, and the Paris Convention for the Prevention of Marine Pollution from Land-Based Sources. It has the general objective of preventing and eliminating pollution of the Maritime Area of the Convention, to ensure that the ecosystems are in a sound and healthy condition, used in a sustainable way, and that human health is protected. The 'Ministerial Meeting of the OSPAR Commission' (1998) expanded the Convention itself by a further Annex which allows for the protection and conservation of the ecosystems and biological diversity of the Maritime Area. In 1998/1999, the OSPAR Commission adopted five strategies that established objectives and requirements for action relating to hazardous substances, radioactive substances, combating eutrophication, the protection of ecosystems and biological diversity, and environmental goals with regard to offshore activities. Amongst other measures, the OSPAR Convention provides for the adoption of legally binding 'Decisions', the first five of which were adopted in 1998.

The OSPAR Strategy to Combat Eutrophication takes up agreements made within the NSC framework, followed through by the Oslo and Paris Commissions and which have been partly fulfilled to date, regarding the reduction of nutrient inputs by about 50%. An important element of the OSPAR strategy is a Common Procedure for the Identification of the Eutrophication Status of the Maritime Area.

OSPAR has agreed on measures for a number of substances (e.g. mercury, hexachloroethane, short chained chlorinated paraffins, PAHs and PCBs) and industrial sectors (e.g. iron and steel, aluminium, PVC , pulp and paper), and has defined BAT or BEP for a number of industrial sectors (e.g. the pulp and paper industry, the aluminium and the non-ferrous metal industry, combustion plants, use of toxic chemicals and pesticides in agriculture and aquaculture).

The OSPAR Strategy with regard to Hazardous Substances takes up agreements made within the NSC framework. This strategy contains provisions for the development of a dynamic selection and prioritisation mechanism to define those hazardous substances where priority action will be taken to continuously reduce discharges, emissions and losses with the ultimate aim of achieving concentrations in the environment near background values for naturally occurring substances and close to zero for man-made synthetic substances. Every endeavour will be made to move towards the target of cessation of discharges, emissions and losses of hazardous substances by the year 2020. OSPAR 1998 also adopted Decisions relating to the disposal of disused offshore installations (see section 3.9) and radioactive discharges (see section 4.8).

Specific OSPAR guidelines for the identification, selection and implementation of measures for Marine Protected Areas (MPAs) are under consideration. However, several other national and international initiatives have led to the establishment of a number of MPAs within the OSPAR maritime area.

The OSPAR Convention prohibits incineration at sea. It also prohibits the dumping of all wastes or other matter except for dredged material, inert materials of natural origin, fish waste and, until the end of 2004, of vessels and aircraft.

The UN Conference on Environment and Development (UNCED 1992, Rio de Janeiro) has made 'sustainable development' an underlying principle in the development of environmental policy. The 'precautionary principle', and the 'polluter pays' principle were introduced on a global level. Agenda 21 was agreed to implement this key idea and to express general policy direction for the 21st century. The 'Rio Declaration' emphasised that States have the sovereign right to exploit their own resources pursuant to their own policies, but also the responsibility of ensuring that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

Environmental policy objectives contained in the

'Amsterdam Treaty' of the EC (1997) are based on the same principles as in the Rio Declaration and articulated in action programmes towards sustainability. While EU environmental policy does not generally address the marine environment per se, many elements of EC environmental legislation have a direct or indirect role in improving the quality of the marine environment as they address the various land-based activities which impact on the marine environment. Successful implementation of the directives on nitrates and urban wastewater would substantively address eutrophication in the marine environment. The various directives on assessment of substances integrated pollution prevention and control and on marketing and use limitations and accident hazards should make a substantial contribution to the realisation of the objective of the OSPAR strategy with regard to hazardous substances. The EU biodiversity strategy, and the birds and habitats directives in principle cover marine species even if so far these have not yet been emphasised. Agreements on total allowable catches (TACs) in the context of the common fisheries policy are the key instrument to ensure maintenance of stocks of target species. Impacts on populations of non-target species and on ecosystems can be addressed by technical measures. OSPAR and the EU are moving towards closer co-operation, *inter alia* in the context of the Water Framework Directive which is currently under preparation.

Eight governmental conferences on the protection of the Wadden Sea have been held since 1978 and have resulted, *inter alia*, in the agreement of a trilateral monitoring and assessment programme, common targets for nature conservation, and cultural and landscape values for this area. Conservation is dealt with in the Trilateral Wadden Sea Cooperation and under EU directives on the conservation on wild birds and on habitat, fauna and flora, by the Ramsar Convention and agreements under the Bonn Convention. National regulation is important on archaeological conservation.

The IMO deals with the safety of shipping and the protection of the marine environment against risks related to shipping. The MEPC deals with issues relating to the prevention and control of pollution from ships. As well as conventions relating to ship safety, IMO has agreed on the 'International Convention for the Prevention of Pollution from Ships' (MARPOL 73/78) which relates to operational discharges from ships.

The 'Bonn Agreement', which first came into force in 1969, was a reaction to major oil spills and aimed to encourage North Sea states to jointly improve their capacity for combating oil pollution. The current Bonn Agreement (1983) is a commitment by North Sea states and the EU to offer mutual assistance and co-operation in combating pollution, and to execute surveillance as an aid to detecting and combating pollution and preventing violations of anti-pollution regulations. In recent years the emphasis has been on the co-ordination of surveillance activities *(see Figure 4.16)*.

The framework for fisheries management within the North Sea is the Common Fisheries Policy (CFP); it will be renegotiated in 2000. In addition, stocks shared between Norway and the EU are managed by separate agreements. Although the 'Intermediate Ministerial Meeting on the Integration of Fisheries and Environmental Issues' 1997 (IMM) has agreed on important guiding principles and strategies to ensure sustainable use of marine living resources, concrete measures to implement them remain to be taken.

chapter 4

Chemistry

4.1 Introduction

In this chapter, the status, spatial distribution and temporal trends of selected compounds and related measures are discussed.

Data were either extracted from relevant OSPAR documents, directly or indirectly from the ICES database as supplied by the Contracting Parties, or taken from the open literature. Priority was given to data produced after 1993, data relevant for establishing spatial distribution and temporal trends and to data relevant for estimating budgets and fluxes.

The mere fact that concentrations are reported at particular locations does not mean that they are of particular concern at these locations. At the same time, data are often unavailable for several areas where the substances under consideration most probably would be present. The compound(s) may simply not have been measured (or reported). This often leads to a gap in information on levels of contamination for the entire North Sea area, and consequently for the calculation of fluxes.

As a general rule, quality assurance has, over the last two decades, been of increasing concern in the process of data acquisition and screening. The improvement of the quality of data is demonstrated, for example, by the decreasing number of outliers in time trends. The possibility that the early data sets may have been ‘contaminated’ by poorer quality data can not be excluded. This cautionary remark is valid for all trace elements (for the period before 1985), and for all trace organic compounds before about 1990. This should be kept in mind when comparing data from different time periods.

4.2 Input of chemical substances in general

In the following text, 'input' refers to the load of substances reaching the estuarine or marine domain. Waterborne inputs are either land-based, occurring at the land/sea interface (riverine and direct inputs), or sea-based, occurring within the marine area itself (from shipping, oil/gas exploration and exploitation, etc.). Airborne inputs at the atmosphere/water interface result from both dry and wet deposition. 'Emission' refers to the release of substances to the atmosphere, while discharges and losses refer to releases into inland waters from point or diffuse sources.

Data from the Comprehensive Atmospheric Monitoring Programme (CAMP) have been used together with data from the Riverine Inputs and direct Discharges programme (RID), in order to establish for the first time an integrated assessment of the atmospheric and waterborne inputs to the North Sea for the period 1990–6 (OSPAR, 1998c).

4.2.1 Land based inputs

Input data such as those collected by the RID programme under the OSPAR Joint Assessment and Monitoring Programme (JAMP) are collected in order to assess, as accurately as possible on an annual basis, all riverine and direct inputs of selected substances from land-based sources to the Convention waters (OSPAR, 1998b). The commitment is to aim for monitoring coverage of at least 90% of the total waterborne input.

Riverine input is the load conveyed by a river at the point of entry to the marine area, which is usually a point of unidirectional freshwater flow immediately upstream of any tidal influence. When loads are estimated at a point situated in the tidal zone, this can lead to some inconsistencies between these estimates and the actual riverine inputs. It is also important to realise that the riverine loads reported represent the loads originating from the entire river catchment area. In the case of trans-national rivers, loads from upstream countries are ascribed to the country furthest downstream.

Direct input is any aquatic input to a river or estuary downstream of the riverine monitoring point or directly into coastal waters.

Estimates of land-based inputs are based on load calculations using river flows and concentrations measured at various (one per river) monitoring stations. When riverine inputs are calculated from measurements conducted upstream of the freshwater limit (gross inputs), processes downstream of the measuring point are not taken into account although they can change the net input considerably. These processes of a physical, chemical or biological nature (flocculation, sedimentation, evaporation, biodegradation, denitrification, etc.) will need to be more accurately described to improve understanding of the riverine inputs to the marine environment. However, though the data established under the RID programme are sometimes incomplete due to gaps in reporting, they provide a useful indication of the orders of magnitude of the inputs. *Table 4.1* provides a summary of direct and riverine inputs to the Greater North Sea.

4.2.2 Sea-based inputs

Inputs from sea-based activities have their origin in particular in shipping, the offshore oil and gas industry, mariculture, and the disposal of dredged material. Some of these inputs may also be of an accidental nature.

Of particular importance is the dumping of dredged material. Due to the huge quantities involved, the loads of contaminants (and nutrients) can be very significant even when the concentrations are low. However, dredged material from harbour areas, estuaries or navigation

Table 4.1 Summary of direct and riverine inputs to the Greater North Sea in 1996. Source of data: OSPAR (1998a).

North Sea Area	Cd (t)	Hg (t)	Cu (t)	Pb (t)	Zn (t)	γ-HCH (kg)	PCBs* (kg)	NH_4-N (10^3 t)
Kattegat								
(lower estimate)			23	7.0	70			
(upper estimate)			23	7.0	704			
Skagerrak								
(lower estimate)	3.1	0.1	104	26	511	34	0	6.5
(upper estimate)	3.2	0.1	104	26	511	34	10	6.5
North Sea (main body)								
(lower estimate)	19	7.2	778	686	4554	690	285	75
(upper estimate)	33	8.4	812	733	4679	735	959	78
Channel								
(lower estimate)	2.4	0.5	151	81	475	135	95	21
(upper estimate)	2.4	0.5	151	81	475	143	97	21

* ΣPCB_7 (sum of IUPAC Nos 28, 52, 101, 118, 153, 138, 180.)

channels may already be accounted for in the land-based inputs. When material is dredged and dumped in the marine area, it concerns merely a remobilisation and relocation of contaminants and nutrients already present. Dredged sediments with low contamination levels have limited anthropogenic influence.

4.2.3 Atmospheric inputs and long range transport and deposition

For a number of contaminants, the airborne inputs constitute an important or even the predominant contribution. This is the case for some heavy metals (especially mercury and lead), persistent organic substances and several nitrogen compounds.

Most substances have a rather short residence time in the atmosphere (in the order of a few days), and they are rapidly deposited by rain (wet deposition) or through sedimentation (dry deposition). The general pattern over the North Sea shows a clear decrease in deposition levels further from the coast and towards open water. The southern regions of the North Sea, close to the industrialised areas, are exposed to particularly high levels of atmospheric deposition. The limited residence time implies that the contribution of more distant, non-OSPAR countries within Europe to atmospheric deposition into the North Sea is small (a few % for heavy metals, 25% for total inorganic nitrogen (OSPAR, 1998c)).

In contrast, some contaminants, such as polychlorinated biphenyls (PCBs), exhibit very long residence times and their atmospheric transport must be considered on a larger, even global, scale.

4.2.4 Transport and fate of contaminants

The fate of contaminants in the North Sea is closely linked to their distribution between the dissolved and the particulate phase. In general, dissolved substances will follow the movements of the respective water masses (see Chapter 2 and *Figure 2.3*).

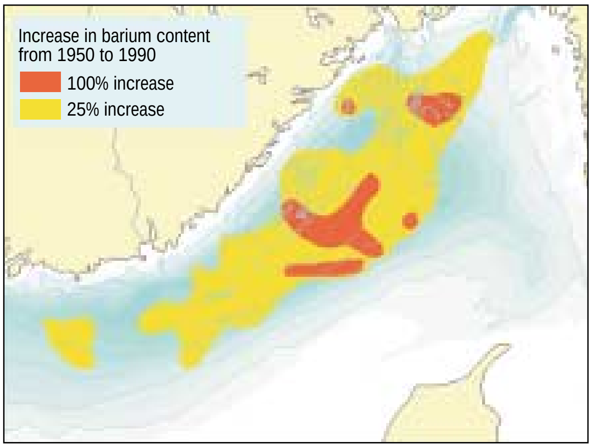
Due to their strong association with particulate matter, the fate of many contaminants in the Greater North Sea is, however, closely related to the transport of (re-)suspended solids. In areas of deposition, sediments are loaded with contaminated particles, and it is estimated that 70% of the substances associated with particulate matter remain trapped in sedimentation areas such as estuaries, the Wadden Sea, the deepest part of the Kattegat-Skagerrak area, and the Norwegian Trench (Laane *et al*., 1998). Barium accumulation in the sediments of the Skagerrak over recent decades *(Figure 4.1)* is an example of transport and deposition of solid material over large areas (Barite, a barium mineral, is a primary component of drilling muds used in the offshore oil industry). Deposited particles will be subject to (bio-)turbation and to resuspension, processes that enhance the release of contaminants. Eventually (contaminated) particles may be subject to burial into deeper layers. There is an ongoing discussion on the importance of these processes, and how to quantify the source and sink functions of sediments.

4.2.5 Persistent contaminants in the food chain

Bioconcentration is the net result of uptake, distribution and elimination of a substance in an organism. It is a key process that influences the fate of persistent and hydrophobic organic contaminants and determines their effect on consumers higher up in the food chain. As a result, such substances (e.g. heavy metals, some organochlorines) are transferred throughout the entire food chain, thus showing highest concentrations in top predators, including man.

NO_3-N (10^3 t)	PO_4-P (10^3 t)	Total N (10^3 t)	Total P (10^3 t)	SPM (10^3 t)
26		41	1.0	
26		41	1.0	
18	0.3	37	1.0	272
18	0.3	37	1.0	272
499	30	729	53	8376
505	32	741	54	8523
87	20	109	10	550
87	20	109	10	550

Figure 4.1 **Increase of barium content in Skagerrak sediments from about 1950 to about 1990. Source: Longva and Thorsnes (1997).**



Identifying and quantifying the most important exposure pathways is rather complex since many factors are involved, including the type of chemical compound, the species of organism and its age, size, feeding habits and individual history.

4.2.6 Quantification of contaminants entering the sea

Riverine inputs are estimated from concentrations and flow rate. In cases where the results recorded are lower than the detection limit of the analytical method, two load estimates (upper and lower values) have been used. The lower estimate is calculated such that any result below the detection limit is considered equal to zero, while for the upper estimate, the value of the detection limit is used. Where this range is wide, it is an indication that most of the concentrations were below the limit of detection, and previous experience has shown that in such a case the upper estimate tends to be unrealistically high.

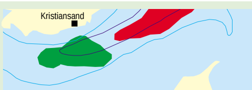
Estimates of atmospheric inputs to the North Sea were based mainly on the results of the CAMP programme. The estimates of wet and dry deposition of nitrogen compounds and heavy metals to the North Sea follow the procedure adopted by the Paris Commission in 1994. In this procedure, the data on contaminant concentrations reported by CAMP coastal measuring stations surrounding the North Sea and the results of long-range transport models are combined. Another approach makes use of models and emission data to estimate atmospheric inputs to the North Sea. For example, heavy metal deposition (excluding mercury) has been estimated using the European Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990 (Berdowski *et al*., 1997) coupled to the Eutrend atmospheric transport model (Van Pul *et al*., 1998).

4.2.7 Time lag between reductions of emissions, discharges and losses and reductions observed in the field

For a number of contaminants, significant reductions in the emissions to the air and discharges to water have been achieved. However, these achievements have not produced an equivalent decrease in the riverine inputs. This situation is partly due to variations in run-off and suspended matter concentration during the period, but it also raises the following two questions: is the contribution of diffuse sources correctly accounted for, owing to the uncertainties in estimating them? to what extent is the mobilisation of contaminants, accumulated over the years in soils, sediments and other land reservoirs (such as flood plains), a possible long-term source of waterborne contaminants? It also highlights that the effectiveness of reduction measures on the actual load reaching the North Sea can only be assessed on a long-term basis.

Similarly, a reduction of contaminant concentrations in the marine system equivalent to the one achieved for emissions, discharges and losses has not been observed, particularly for sediments and biota. A variety of models have been developed to assess contaminant transport and fate in the North Sea (OSPAR, 1998d). In a model simulation based on a 50% reduction of the cadmium load from rivers and atmospheric deposition, a decrease of less than 15% in environmental concentrations was obtained at seven locations throughout the North Sea *(Table 4.2)*. The largest decreases in concentration were found in the coastal zones where river discharges are the dominant source of contaminants. Models indicate the smallest decreases (1 – 4%) occurring in the central and northern North Sea, where river influence is small and Atlantic inflow over the boundaries is the major source. In general, water flowing into the Greater North Sea from the Atlantic has a major influence on the amount of trace metals and nutrients in the North Sea because of the large volume involved.

Table 4.2 Results of reduction scenario for cadmium. Source: OSPAR (1998d).



Location (see map)	Model 1	Model 2	Model 3	Model 4	Model 5
UK coast (1)	6	1	4	1	6
Dutch coast (2)	8	8	12	16	13
South Central North Sea (3)	6	3	6	3	9
German Bight (4)	9	4	8	6	8
Central North Sea (5)	1	2	1	1	4
German Bight North (6)	9	5	8	7	10
UK Coast –Southwestern North Sea (7)	3	4	4	1	4

Model simulation of a 50% reduction of the riverine cadmium input (relative to 1989)

The figures given are in % reduction in the seawater dissolved Cd concentration

Model 1	BSHdmod.E (BSH Germany)
Model 2	NORWECOM (IMR Norway)
Model 3	NOSTRADAMUS (SOC United Kingdom)
Models 4 and 5	SCREMETOX and ZeeBOS-TOX (Rijkswaterstaat – Delft Hydraulics, The Netherlands)

4.2.8 Concentrations and Trends

Concentrations of substances in sediments are generally reported in relation to dry weight (dw) and concentrations in biota in relation to wet weight (ww), dry weight or fat weight (fw).

Trends for contaminants in biota were calculated for time series of minimum 4 years and based on a 95% level of confidence (OSPAR, 2000).

Table 4.3 **Ranges in the background concentrations of cadmium, mercury, lead and copper within the OSPAR maritime area. Source: OSPAR (1997b).**

	Sediments relative to Al (*10^{-4})	Seawater (ng/kg)	Blue mussel (mg/kg ww)
Cd	0.007 – 0.030	8 – 25	0.07 – 0.11
Hg	0.0034 – 0.0066	0.2 – 0.5	0.005 – 0.010
Pb	1.8 – 4.0	10 – 20	0.01 – 0.19
Cu	2.2 – 5.7	50 – 360	550.76 – 1.10

4.3 Background/reference values in water, sediments and biota and assessment tools

To help in the assessment of the ecological impact of contaminants, Background/Reference Concentrations (BRCs) and Ecotoxicological Assessment Criteria (EACs) have been developed at OSPAR workshops. In 1997 OSPAR endorsed BRCs and EACs for a number of substances together with guidance for their use.

Some of these BRC or EAC values are firm while others are still preliminary, but whenever available, they have been related to the observed concentrations.

4.3.1 Background/Reference Concentrations

Naturally occurring substances are defined as all substances produced from natural precursors by biosynthesis, geochemical or (photo) chemical processes. The BRC for naturally occurring substances is defined as the concentration that could be found in the environment in the absence of any human activity. This means that for anthropogenic substances the natural background concentration should, in theory, be zero, but due to historic contamination (e.g. as in the case of PCBs) the adopted BRC may have a (reference) value above zero. BRCs were defined preferably from data from geological or historical times and/or from pristine regions found within the Convention Area. BRCs (if available) for trace metals and trace organic compounds in water, sediment and biota (mussel tissue) are summarised in *Tables 4.3*, *4.4* and *4.5*.

Assessment of nutrient data is difficult, because few reliable data exist from times of low anthropogenic influence, i.e. before 1950. *Table 4.6* provides some of these data on winter concentrations on a local basis. However, OSPAR has not endorsed these values as BRCs.

Background concentrations of various natural radionuclides are provided in section 4.8.

4.3.2 Ecotoxicological Assessment Criteria

EACs were established for assessing chemical monitoring data from the OSPAR Convention area. EACs are the concentrations of specific substances in the marine environment below which no harm to the environment or biota is expected. Criteria for the specific contaminants were derived using all the available ecotoxicological data that passed predefined quality criteria (OSPAR, 1996).

Table 4.4 **Background concentrations of selected polycyclic aromatic hydrocarbons (PAHs) in surface sediments from remote areas and in surface water for application in specific regions of the North Sea. Source: OSPAR (1997b).**

	Sediments (ng/g dw)		Water (ng/l)	
	Northern North Sea/Skagerrak	Southern North Sea	Northern North Sea	Central and Southern North Sea
Benzo[*a*]pyrene	8.8 – 112	< 0.2 – 51	0.002 – 0.005	0.002 – 0.004
Fluoranthene	14 – 160	0.72 – 97	0.073 – 0.285	0.104 – 0.264
Benzo[*b* + *k*]fluoranthene	46 – 434	1.1 – 142	–	–
Benzo[*b*]fluoranthene	–	–	0.004 – 0.017	0.003 – 0.009
Indeno[*1,2,3*]pyrene	43 – 212	< 0.2 – 70	0.004 – 0.017	0.006 – 0.012

Table 4.5 **Ranges of background/reference concentrations of hexachlorobenzene (HCB), pp'–dichlorodiphenyldichloroethene (DDE) and selected polychlorinated biphenyls (PCBs) in surface sediments (pg/g dw) of selected areas from the North Sea. Source: OSPAR (1997b).**

	HCB	PCB-28	PCB-52	PCB-101	PCB-153	PCB-138	PCB-180	DDE-pp
South Norway/Skagerrak	70	31	32	62	90	116	60	66
German Bight	910	680	260	730	1650	1200	600	510

Table 4.6 Ranges in the pre-1950 background winter concentrations of dissolved phosphate, nitrite, nitrate and silicate (µmol/l, winter values) in different areas of the North Sea. Source of data: OSPAR (1997j).

	Salinity	PO_4	SiO_4	NO_2	NO_3
Strait of Dover	34.5 – 35.2	0.42 – 0.57	2.5 – 7.0	0.1 – 0.9	4.8 – 11.1
Netherlands coast	31 – 33	0.48 – 0.90	9 – 21	0.05 – 0.70	19.5 – 32.2
German Bight	31 – 33	0.43 – 0.60	9 – 17	0.4 – 1.2	–
Southern Bight	> 34.5	0.25 – 0.70	2.5 – 10.5	0.03 – 15.4	1.5 – 10
Dogger Bank	–	0.35 – 0.80	2.5 – 7.1	< 0.6	–

Table 4.7 Overview of ecotoxicological assessment criteria. Source: OSPAR (1997b).

	Water (mg/l)	Sediment (mg/kg dw)	Mussel (mg/kg dw)
Trace metals			
As	1 – 10*	1 – 10†	nr
Cd	0.01 – 0.1*	0.1 – 1†	fc
Cr	1 – 10*	10 – 100†	nr
Cu	0.005 – 0.05*‡	5 – 50†	fc
Hg	0.005 – 0.05*	0.05 – 0.5†	fc
Ni	0.1 – 1†	5 – 50†	nr
Pb	0.5 – 5*	5 – 50†	fc
Zn	0.5 – 5*	50 – 500†	nr
Organochlorine pesticides			
DDE	nr	0.0005 – 0.005†	0.005 – 0.05*
Dieldrine	nr	0.0005 – 0.005†	0.005 – 0.05*
Lindane	0.0005 – 0.005*	nr	nr
PAHs			
Naphthalene	5 – 50*	0.05 – 0.5*	0.5 – 5†
Phenanthrene	0.5 – 5†	0.1 – 1*	5 – 50†
Anthracene	0.001 – 0.01†	0.05 – 0.5*	0.005 – 0.05†
Fluoranthene	0.01 – 0.1†	0.5 – 5†	1 – 10†
Pyrene	0.05 – 0.5†	0.05 – 0.5†	1 – 10†
Benzo[*a*]anthracene	nd	0.1 – 1†	nd
Chrysene	nd	0.1 – 1†	nd
Benzo[*a*]fluoranthene	nd	nd	nd
Benzo[*a*]pyrene	0.01 – 0.1†	0.1 – 1†	5 – 50†
Benzo[*ghi*]perylene	nd	nd	nd
Indeno[1,2,3-*cd*]pyrene	nd	nd	nd
$\sum PCB_7$	nr	0.001 – 0.01†	0.005 – 0.058
TBT	0.00001 – 0.0001*	0.000005 – 0.00005†	0.001 – 0.01*

* firm; † provisional; ‡ this bracket is within the range of background values for natural waters. This value should be compared with the bioavailable fraction in sea water; fc for future consideration; nr not relevant to the current monitoring programme; nd no data available or insufficient data available.

Cautionary note: These assessment criteria have no legal significance and should only be used for the preliminary assessment of JMP/JAMP chemical monitoring data with the aim of identifying potential areas of concern. When applied, the fact whether an EAC is firm or provisional should be taken into account.

Objectives for these assessment criteria should be, in general, to identify possible areas of concern, to indicate which substances could be considered a priority, to determine whether effects on biota are likely to occur. EACs for selected trace metals, PCBs, PAHs, tributyltin (TBT) and some organochlorine pesticides in water, sediment and biota (mussel tissue) are given in *Table 4.7*.

Although 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. However, caution should be exercised in using generic, particularly provisional, assessment criteria in specific situations since their use does not preclude the use of common sense and expert judgement with regard to natural concentrations. Furthermore, the EACs do not take into account specific long-term biological effects such as carcinogenicity, genotoxicity and endocrine disruption, or the combined effects of substances.

4.3.3 Trend detection of data sets

Trends for contaminants in biota were calculated for time series of at least 4 years and based on a 95% level of confidence (OSPAR, 2000). It is worthwhile noting that, despite the large number of these time series available, only few data sets revealed significant trends (e.g. 5 – 10% in the case of metals). The large number of non-significant trends might originate from too rigorous statistical requirements, from the fact that most time series are still too short to reveal reliable information on trends, from a high natural variability of contaminant levels in the organisms monitored, or from insufficient sampling frequency.

4.4 **Heavy metals**

4.4.1 Fluxes and transport routes of heavy metals

Heavy metals reach the North Sea via both airborne and waterborne inputs. Inputs are also generated by some sea-based activities, such as exploitation of offshore resources and dumping of dredged materials.

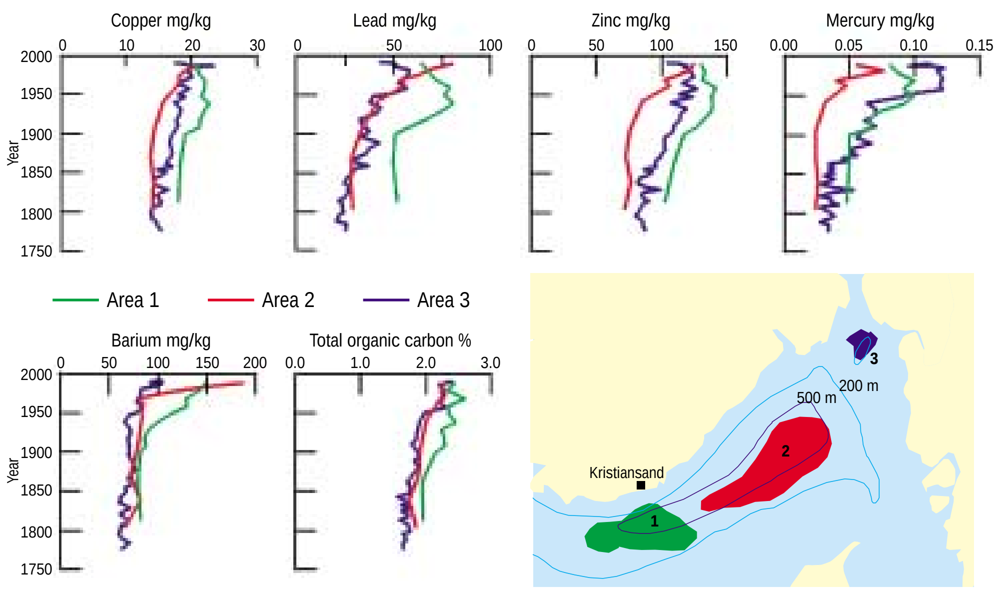
Typical atmospheric deposition levels at around 500 km from the coasts are an order of magnitude lower than deposition into coastal waters close to industrialised areas.

The riverine fluxes of metals consist of particulate and dissolved species. The particulate phase is predominant for most elements. The spatial distribution of metals in the coastal zones, where highest concentrations are found near fresh water outlets and lowest in the open sea, suggests that rivers are major sources of trace metals. However, the dumping of dredged material can disturb this pattern locally.

A decline in the concentration of various metals has generally been observed in the surface sediments in dynamic sediment zones. This is due to mixing with less contaminated suspended matter or the winnowing of contaminated particles.

The recent history of heavy metal accumulation can be observed in (net) deposition areas, such as the Skagerrak and Norwegian Trench. In the deepest part of the Skagerrak (area 2 in *Figure 4.2*), mercury concentrations in sediments have increased significantly since about 1950, while increases in lead and copper concentrations began somewhat earlier, around 1900. Apart from the changes in the contaminant load to these areas over recent decades, a number of other factors have influenced the observed pattern, including variations in sediment transport and erosion rates, and eutrophication and environmental changes in the deeper part of the Skagerrak.

Figure 4.2 **Stratigraphic plot of heavy metals concentration in sediments of the Skagerrak – Norwegian Trench Area. Source: Longva and Thorsnes (1997).**



4.4.2 Cadmium (Cd)

Sources and input estimates

During the period 1990–6, the riverine inputs of cadmium did not show a discernible change, but the direct inputs (which only contribute about 5% to the total waterborne inputs) have decreased markedly *(Figure 4.3)*. *Table 4.8* gives examples of the proportion of riverine and direct inputs, and the difference between lower and upper estimates in two different years. The total cadmium input did not follow a consistent trend *(Figure 4.3)*, mainly because of variations in runoff and suspended particulate matter concentrations. In the Skagerrak area, cadmium inputs remained in the 2 – 5 t/yr range. Inputs to the Wadden Sea by the rivers Elbe and Ems significantly decreased between 1985 and 1995 (Bakker *et al*., 1999). For 1992, the input into the German Bight was estimated to be about 10 t, with a contribution of 6.2, 3.4 and 0.33 t from the Elbe, Weser and Ems, respectively (Radach and Heyer, 1997).

Atmospheric deposition of cadmium is responsible for about one third of the total cadmium input into the Greater North Sea. Wet deposition at coastal stations has shown a decrease of around 50% between the late 1980s and the early 1990s. No significant decrease of cadmium input has been observed for dry deposition. The total atmospheric emission and deposition was halved between 1987 and 1995 (*Figure 4.4* and *Table 4.9*). Model computations indicate that the Southern Bight of the North Sea receives more than 50% of the atmospheric inputs (Van Pul *et al*., 1998). It is also estimated that 94% of the atmospheric emissions reaching the North Sea originate from OSPAR Contracting Parties.

Figure 4.3 **Total waterborne cadmium input to the Greater North Sea (t/yr). Source of data: lower estimates of riverine and direct inputs in OSPAR (1998c).**

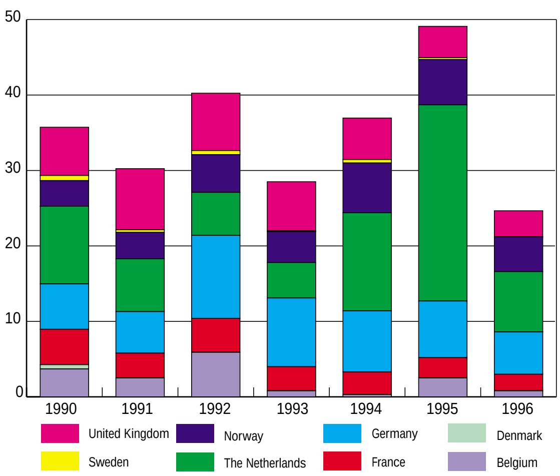


Table 4.8 **Riverine and direct inputs of cadmium to the Greater North Sea in 1990 and 1996. Source of data: OSPAR (1998c).**

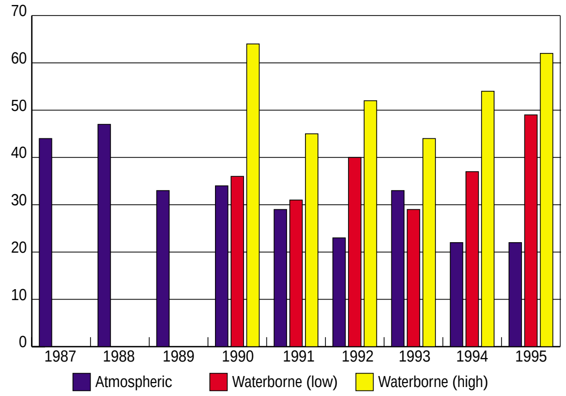
	Riverine inputs (t)		Direct inputs (t)	
	1990	1996	1990	1996
Belgium	3.7* 4.9**	0.8* 5.0**	-	-
Denmark	0.48	n.i.	0.085	n.i.
France	4.7	2.2	n.i.	n.i.
Germany	6.0*§ 11.0**§	5.6§	0.02* 0.06**	0.02* 0.07**
Netherlands	9.8§	8.2§	0.5	0.2
Norway	2.7* 15.6**	3.5* 3.8**	0.7	1.1
Sweden	0.57	0.24	0.1	0.021
United Kingdom	2.7* 7.7**	2.3* 11.4**	3.7* 7.6**	1.16* 1.46**
TOTAL‡				
Lower estimate*	31	23	5.1	2.5
Upper estimate**	55	36	9.1	2.8

§ Including loads from countries upstream.
‡ Total rounded to two significant digits.
* Lower estimate: for concentrations less than the detection limit, a value of '0' was used when calculating loads.
** Upper estimate: for concentrations less than the detection limit, the value of the detection limit was used when calculating loads;
n.i. no information.

Note: Some 1990 data updated by OSPAR may differ from those reported in the 1993 QSR.

Five North Sea numerical models of the transport and fate of riverine contaminants were compared (OSPAR, 1998d). For the year 1989, model results for dissolved cadmium were compared with field measurements from the NERC North Sea Project (NSP) and total cadmium fluxes through the North Sea were calculated *(Table 4.10)*. For dissolved cadmium the modelled concentrations were quite similar (in the range of 0.01 – 0.03 µg/l) but consistently lower than the measured field concentrations, indicating possible underestimation of cadmium boundary conditions for the models. There are differences between mass balances provided by the models. However, all models calculated that the overall riverine cadmium load is of the same order of magnitude as atmospheric inputs but about one order of magnitude

Figure 4.4 **Estimates of cadmium inputs to the North Sea (t/yr). Source: OSPAR (1998c).**



less than the mass inflow from outside the region with Atlantic water.

Ranges of cadmium concentrations are summarised in *Figure 4.5*.

Concentrations in water

Scholten *et al*. (1998) compared the overall mean concentrations of dissolved cadmium in the entire North Sea for 1982–5 and 1986–90, and found a major reduction in concentrations of this metal (50%), although improvements in analytical procedures may interfere with the proper estimation of this trend. Large decreases were observed, especially in the Southern Bight, and also in the Dutch coastal zone, the Thames estuary and the Dogger Bank area.

Concentrations in sediments

In the Dutch coastal zone, the cadmium content has significantly decreased in the areas with previously highest concentrations (Laane *et al*., 1998). Between 1981 and 1996, the median concentration fell by 71% in the area north of the mouth of the Rhine and Meuse rivers. South of this mouth, the median concentration fell by 45%. No significant decrease was found 20 – 70 km offshore in the open sea.

In the Scheldt estuary, a very strong upstream gradient was still measured between Vlissingen and Antwerp, but the maximum concentration decreased by a factor of 3 between 1990 and 1995 (Vyncke *et al*., 1997). Between 1988 and 1993, cadmium concentration in the sediments of the Wadden Sea generally decreased by 10-40% (Bakker *et al*., 1996).

Concentrations in biota

Based on data up to 1996, 65 time series of up to 15 years length were assessed for the Greater North Sea

Table 4.9 Atmospheric emissions of selected heavy metals (t/yr). Source: 4NSC (1995).

Country	Cadmium			Mercury			Lead			Copper		
	1985	1990	1995(+)	1985	1990	1995(+)	1985	1990	1995(+)	1985	1990	1995(+)
Belgium (*)	12.8	6.8	5.4	14.1	9.5	8.0	1707	794	605	157	99	87
Denmark (#)	> 2.2	0.1	–	> 3.3	0.5	–	305	34	–	> 15	5	–
France		no data			no data			no data			no data	
Germany (#)	37.0	10.0	<10	37.0	28.0	<28	5004	838	<838	95	55	<55
The Netherlands (*)	4.3	–	1.9	11.5	–	5.4	1334	–	219	67	–	65
Norway(*)	1.0	0.4	0.4	1.6	0.4	0.4	417	109	10	17	2	2
Sweden (#)	1.0	0.4	0.3	0.9	0.3	0.3	110	25	40	14	5	5
Switzerland (#)	4.7	2.9	1.9		no data		680	440	260		no data	
United Kingdom (#, §)	78	73	59	29.3	27.9	12.8	8120	3190	1320	676	633	574
TOTAL (†)	140	94	79	98	67	55	18000	5400	3300	1000	800	780

* point and diffuse sources; # point sources; + projected values; § min. values; † rounded to two significant digits.

Table 4.10 Modelled mass balance for cadmium in the North Sea (t/yr). Source: OSPAR (1998d).

	Model 1	Model 2	Model 3	Model 4	Model 5
Mass In					
Straight of Dover	52	100	66	83	85
Rivers	12	16	17	13	27
Atmospheric deposition	20	10	13	10	9
Offshore		0	0	2	0
Total Mass In	104	126	96	108	121
Mass Out					
N. Boundary (net) (56°N)	70	40	90	93	119
Sedimentation (net)	0	83	9	14	19
Total Mass Out	70	123	99	106	138
NET (in - out)	34	3	-3	1	-17

Model 1 BSHdmod.E (BSH Germany)
Model 2 NORWECOM (IMR Norway)
Model 3 NOSTRADAMUS (SOC United Kingdom)
Models 4 and 5 SCREMETOX and ZeeBOS-TOX (Rijkswaterstaat – Delft Hydraulics, The Netherlands)

area (OSPAR, 2000). No upward trends were found anywhere, but four significant downward trends were found in blue mussels from the Netherlands (Western Scheldt and Ems-Dollard area) and Norway (Sørfjord and Hardangerfjord). For the remaining time series, no statistically significant trends could be determined. A rapid reduction in the concentration of cadmium in mussels was measured in the Seine estuary after phospho-gypsum discharges were prohibited in 1992. Mean levels decreased by more than 50% in a 3 year period.

Significant downward trends were found in flounder livers from the Western Scheldt and the inner Sørfjord, and in cod livers from Fladen in Sweden (OSPAR, 2000).

Reference to EAC and BRC

Dissolved cadmium concentrations in seawater are generally well below the higher EAC limit and within the range of the agreed BRC levels *(Figure 4.5)*. In some estuaries, BRC values can be exceeded by a factor 2 – 10 and the higher EAC limit may be approached (Seine) or exceeded (Scheldt) at the location of maximum cadmium concentration.

In sediments, EAC values were exceeded at some locations near the mouth of the Rhine, in the Dutch Wadden Sea and in the Scheldt estuary.

Comparing the cadmium concentrations in mussel tissue with the BRC, the means of 46 out of 58 data sets were above the BRC. In the Tay and Forth estuaries, the BRC was exceeded by a factor of 2 – 3 and in the Seine estuary by a factor of 5. Highest ratios occurred in Norwegian fjords (Sørfjord: 95-fold, Hardangerfjord: 20-fold), due to the presence of smelting industries. In the Sørfjord there is still advice against consumption of blue mussels due to high cadmium (and lead) levels.

4.4.3 Mercury (Hg)

Sources and input estimates

Both riverine and direct inputs of mercury show a decreasing trend between 1990 and 1996. *Table 4.11* gives examples of the proportion of riverine and direct inputs, and the difference between lower and upper estimates in two different years. Inputs to the Skagerrak and Kattegat are low compared to inputs to the North Sea region. From 1990–3 aquatic inputs were dominated by the Elbe whereas from 1993–6 inputs from the Rhine-Meuse dominated (OSPAR, 1998b).

Since the mid-1980s, technical improvements in production technology have lead to a significant decrease in mercury emissions *(Table 4.9)*. This is also due to important mercury emitters in the former German Democratic Republic being closed down.

Calculated atmospheric input showed a decrease from 9 to 4 t/yr between 1987 and 1995 *(Figure 4.6)*. Dry deposition of mercury was not monitored but is estimated to account for 10% of the total deposition onto the sea (Petersen *et al.*, 1995).

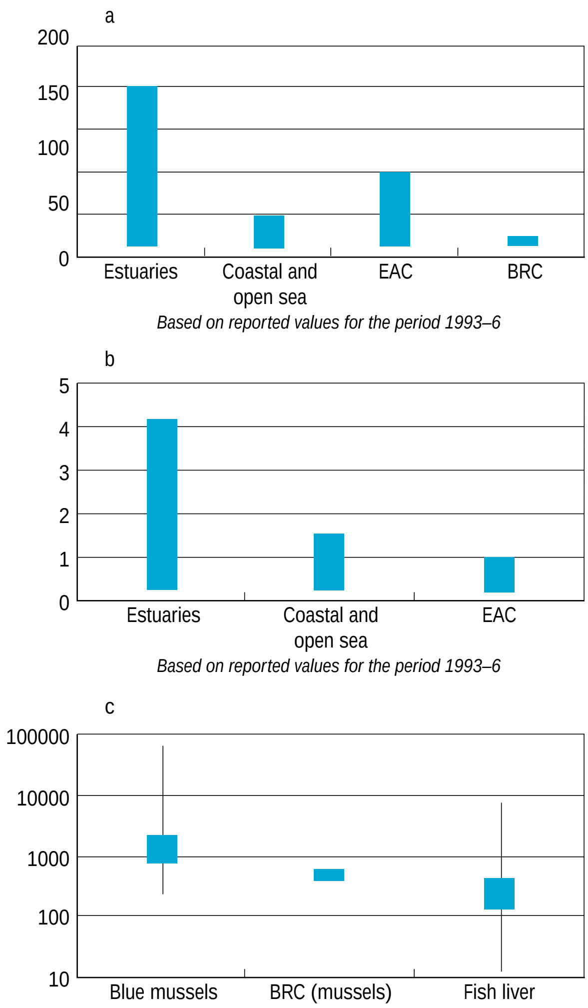
In the sea, mercury ions can be converted into volatile mercury and emitted to the atmosphere. The resulting flux of mercury is estimated to be 4 – 10 t/yr, comparable to wet and dry deposition (Baeyens and Leermakers, 1998).

Mercury concentrations are given in *Figure 4.7*.

Concentrations in water

Mercury concentrations range from more than 1 ng/l at the mouth of estuaries to 0.1 ng/l in open seawater. Particulate mercury accounts for over 90% of the total mercury in coastal waters and decreases to less than 10% in the less turbid open sea.

Figure 4.5 **Cadmium concentrations: (a) in water (ng/l). Concentration ranges, EAC (firm) and BRC; (b) in sediments (mg/kg). Concentration ranges and EAC (provisional); (c) in biota (ng/g dw). Concentration ranges and upper and lower quartiles. Source: OSPAR (2000).**



Based on 189 median yearly values for the period 1993–6. The bar indicates the data range and the box the data between the 25 and 75 percentile. The BRC range is also shown as a box.

In coastal areas, particulate mercury concentrations are highly variable, ranging from 0.05 – 1.0 mg/kg. In the open sea, they generally range from 0.02 – 0.20 mg/kg.

Important decreases in particulate mercury concentrations were observed in the river Elbe, from 20 – 80 mg/kg prior to 1990 to 5 – 10 mg/kg after 1992 (Wilken and Wallschläger, 1996), and were comparable to those in the Seine and the Scheldt estuaries.

A fraction of the mercury may be present in the more toxic methylated forms. Dissolved monomethyl-mercury (MMHg) concentrations range from up to 600 pg/l in estuaries to less than 10 – 60 pg/l in the open sea. Particulate MMHg concentrations range from less than

Table 4.11 Riverine and direct inputs of mercury to the Greater North Sea in 1990 and 1996. Source of data: OSPAR (1998c).

	Riverine inputs (t)		Direct inputs (t)	
	1990	1996	1990	1996
Belgium	3.6* 4.5**	0.02* 0.03**	n.i.	0.00
Denmark	0.042	n.i.	0.091	0.001
France	5.7	0.5	n.i.	n.i.
Germany	10*§ 11*§	2.9§	0.02* 0.05**	0.01* 0.07**
Netherlands	3.1§	3.2§	0.08	0.08
Norway	0.04	0.13	0.5	0.09
Sweden	0.072	n.i.	0.033	0.023
United Kingdom	0.9* 3.4**	0.5* 1.7**	0.8* 0.9**	0.2* 0.3**
TOTAL				
Lower estimate	19*	7.25*	1.5*	0.40*
Upper estimate	49**	8.46**	1.7**	0.56**

§ Including loads from countries upstream.
* Lower estimate: for concentrations less than the detection limit, a value of '0' was used for calculating load.
** Upper estimate: for concentrations less than the detection limit, the value of the detection limit was used.
n.i. no information.

0.001 – 0.010 mg/kg (Baeyens, 1998). On the basis of the available data, no significant regional variability can be found.

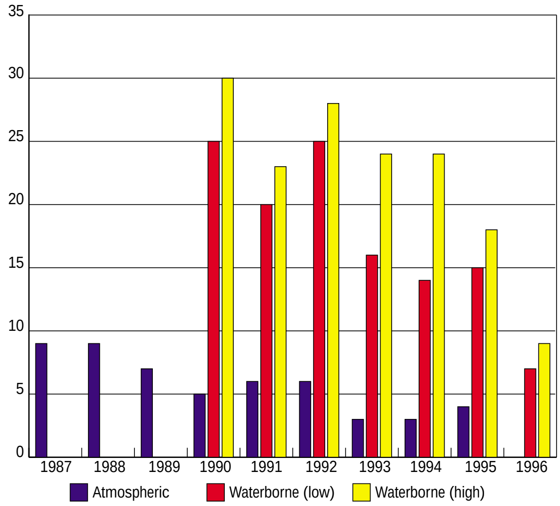
Due to major improvements in the methods applied, monitoring results of the 1980s are inconsistent with those of recent years. Hence, trends cannot be established.

Concentrations in sediment

Mercury concentrations in sediments typically range from 0.01 – 0.5 mg/kg. Higher concentrations are found in the estuaries of the Scheldt, Forth, Elbe and Thames as well as at near-shore stations and dredged spoil disposal sites.

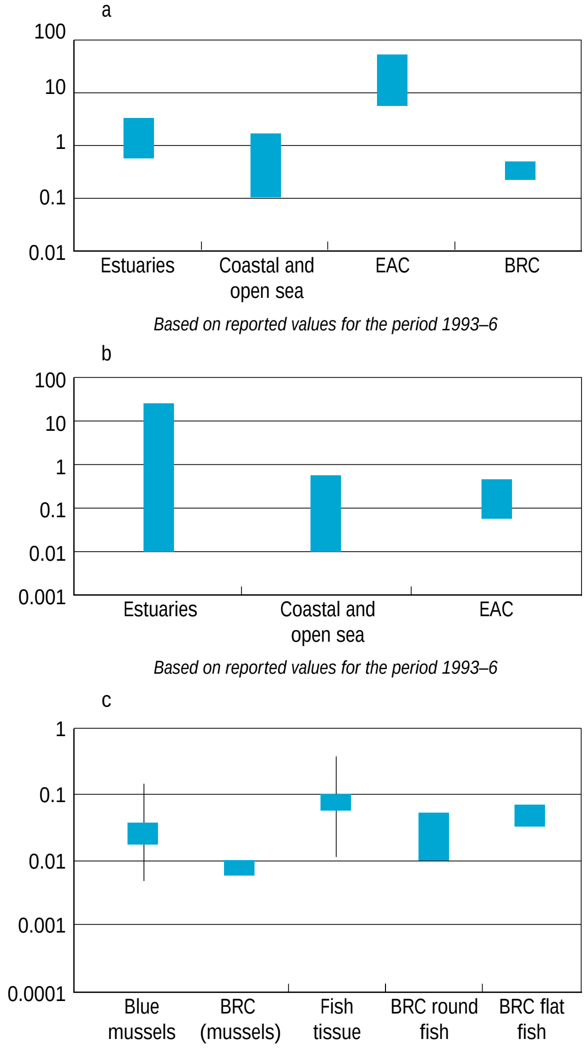
Mercury concentrations at former sewage sludge disposal sites in the inner German Bight show a clearly decreasing trend. In the Belgian coastal area, a downward trend in mercury concentrations at the disposal sites was noted in the period 1979–95 (a 5% annual decrease), whereas for the other coastal stations and the Scheldt estuary decreases were insignificant.

Figure 4.6 **Estimates of mercury inputs to the North Sea (t/yr). Source: OSPAR (1998c).**



Atmospheric inputs are based on wet deposition measurements at coastal stations and calculated for an area of 525 000 km^2. Lower and higher estimates are reported for total waterborne inputs (riverine inputs + direct discharges).

Figure 4.7 **Mercury concentrations: (a) dissolved mercury in water (ng/l). Concentration ranges, EAC (firm) and BRC values; (b) in sediments (mg/kg dw). Concentration ranges and EAC (provisional); (c) in biota (mg/kg ww). Concentration ranges and upper and lower quartiles. Source: OSPAR (2000).**



Based on median yearly values for the period 1993–6. The bar indicates the data range and the box the data between the 25 and 75 percentile. The BRC range is also shown as a box.

Concentrations in biota

Eighty-six time series of mercury in blue mussels and fish covering the period 1978–96 were assessed (OSPAR, 2000). After having passed through severe statistical tests only eight significant time trends were detected, all downward except for one from mussels in the Sørfjord. Significant downward trends were found in time series for flounder from the Belgian coast, the Ems-Dollard, the Wadden Sea and the Elbe, as well as in plaice from the Southern Bight of the North Sea.

In general, blue mussel data show elevated concentrations in the vicinity of industrial and densely populated areas. In Norway, relatively higher concentrations are found in the industrial areas of the Sørfjord, in the inner parts of the Hardangerfjord and the Oslofjord. Low concentrations are found along the Swedish and the German North Frisian coasts. The Elbe estuary is severely influenced by discharges from industrial areas in the former GDR and the Czech Republic. The southern coasts of the North Sea, from the mouth of the river Elbe as far as France, show comparable concentrations, but with elevated concentrations in the Seine estuary.

Mercury in fish tissue occurs mostly in the MMHg form. However, juvenile fish, shrimp, mussels and sea urchins have lower MMHg fractions (e.g. up to 40% in mussels).

Reference to EAC and BRC

Dissolved mercury concentrations in seawater and estuaries seldom exceed lower EAC limits. In offshore stations, they are comparable to the BRC. In coastal zones and estuaries, they can exceed the BRC by a factor 2 – 10. Particulate mercury concentrations can exceed upper EAC limits in high turbidity areas, such as in estuaries.

The upper EAC limits were exceeded in a number of sediments from the estuaries of the Scheldt, Elbe and Forth and lower limits were exceeded at the disposal sites for dredged spoil. Enrichment factors (mean concentration at site divided by the BRC) range from 1 – 7 in coastal and offshore sediments and from 10 – 50 in contaminated estuarine stations.

Blue mussel data sets show systematic elevated concentrations with respect to BRCs. Highest enrichment factors in Norway occur in the industrial areas of Sørfjord (up to 11) and at one site in the Oslofjord (up to 4.5). Along the coast, from the mouth of the river Elbe to France, enrichment factors range from 2 – 7. Low ratios (1 – 3) occur all along the Swedish coast and in the North Frisian area.

In general, data sets for fish muscle tissue show values close to BRCs (enrichment factor less than 2). For Norwegian data series, enrichment factors are less than 3 except for a time series in dab from Borøy (5), and for one in cod from the inner Sørfjord (3). Enrichment factors are in many cases lower along the Swedish and Danish coasts (less than 2). German time series show enrichment factors up to 3. Dutch time series range close to the BRC. For Belgium and France, enrichment factors of less than 4 are observed.

4.4.4 Lead (Pb)

Sources and input estimates

During the period 1990–6, the direct inputs of lead to the Greater North Sea were halved. However, they only contributed about 10% of the total input. *Table 4.12* gives examples of the proportion of riverine and direct inputs, and the difference between lower and upper estimates in two different years. The total annual loads decreased slightly (from 1000 to 800 tonnes), but the mean value over the period remained high (1 200 tonnes) *(Figure 4.8)*. In the Skagerrak area, lead inputs which varied in this period between 25 and 37 t/yr showed an increasing trend. Inputs to the Wadden Sea by the Elbe have strongly decreased since 1993, but in the Weser there has been a significant increase in inputs since the beginning of the 1990s (Bakker *et al*., 1999).

Measurements of wet, dry and total atmospheric deposition at coastal stations showed a decrease of 50 – 65% between 1987 and 1995 *(Figure 4.9)* This confirms a major decrease in emissions *(Table 4.9)*, with most of the reduction having occurred before 1990 (OSPAR, 1998c). The values for the mid 1990s are in the range 700 – 900 t/yr, indicating that the atmospheric inputs are not larger than the riverine inputs, as they were before 1990. Model computations indicate that 98 – 99% of the airborne lead reaching the North Sea originates from OSPAR Contracting Parties and that the Southern Bight receives more than 50% of the atmospheric inputs (Van Pul *et al*., 1998).

Lead concentration ranges are summarised in *Figure 4.10*.

Concentrations in water

Scholten *et al*. (1998) found an overall reduction of 38% in concentrations of dissolved lead in time series for the entire North Sea between the periods 1982–5 and 1986–90. Large decreases were observed around the Skagerrak, Dogger Bank, Dutch coast and Thames estuary.

Table 4.12 Riverine and direct inputs of lead to the Greater North Sea in 1990 and 1996. Source of data: OSPAR (1998c).

	Riverine inputs (t)		Direct inputs (t)	
	1990	1996	1990	1996
Belgium	24* 31*	29* 60**	n.i.	0.009
Denmark	5.1	n.i.	2.12	n.i.
France	150	66	n.i.	n.i.
Germany	212§	125§	0.5* 1.0**	1.2* 1.8**
Netherlands	340§	380§	6.5	2.9
Norway	45* 91**	33	10	4.1
Sweden	7.8	7.5	0.5	0.5
United Kingdom	109* 131**	100* 120**	80.6* 107**	49.5* 50.5**
TOTAL‡				
Lower estimate*	890	740	100	58
Upper estimate**	970	790	130	60

§ Including loads from countries upstream.
‡ Total rounded to two significant digits.
* Lower estimate: for concentrations less than the detection limit, the value '0' was used when calculating loads.
** Upper estimate: for concentrations less than the detection limit, the value of the detection limit was used when calculating loads.
n.i. no information.
Note: Some 1990 data updated by OSPAR may differ from those reported in the 1993 QSR.

Concentrations in sediments

Between 1981 and 1996, the median concentration of lead dropped by 53% in the Dutch coastal zone north of the mouth of the Rhine (Laane *et al*., 1998). Outside the Rhine plume, no significant decrease has been found.

In the Belgian coastal zone, the lead concentration was about 25% less in 1995 than the mean value observed in 1990. In the Scheldt estuary, a strong downward gradient was measured from Antwerp to Vlissingen. Between 1990 and 1995, the concentrations decreased by a factor of 1.5 – 3 (Vyncke *et al*., 1997). In

Figure 4.8 **Total waterborne lead input to the Greater North Sea (t/yr). Source of data: lower estimates of riverine and direct inputs in OSPAR (1998c).**

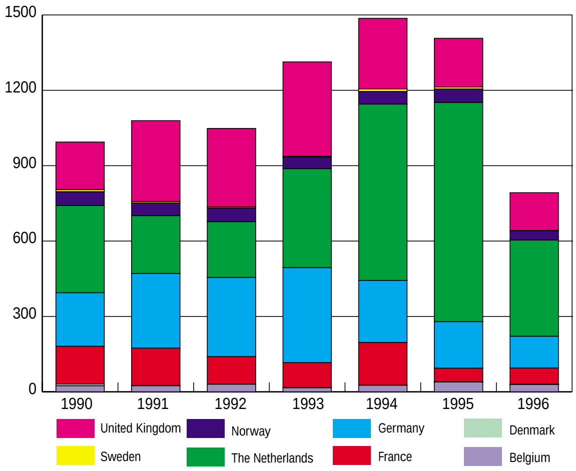
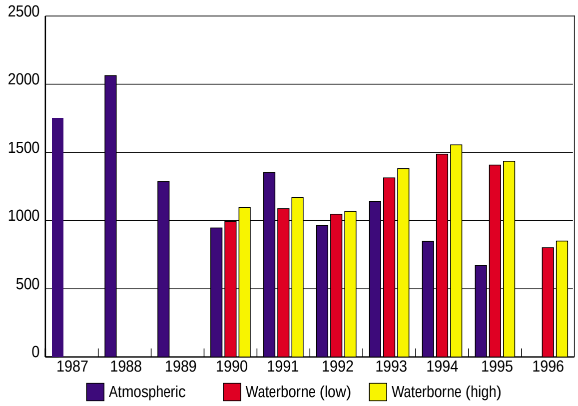
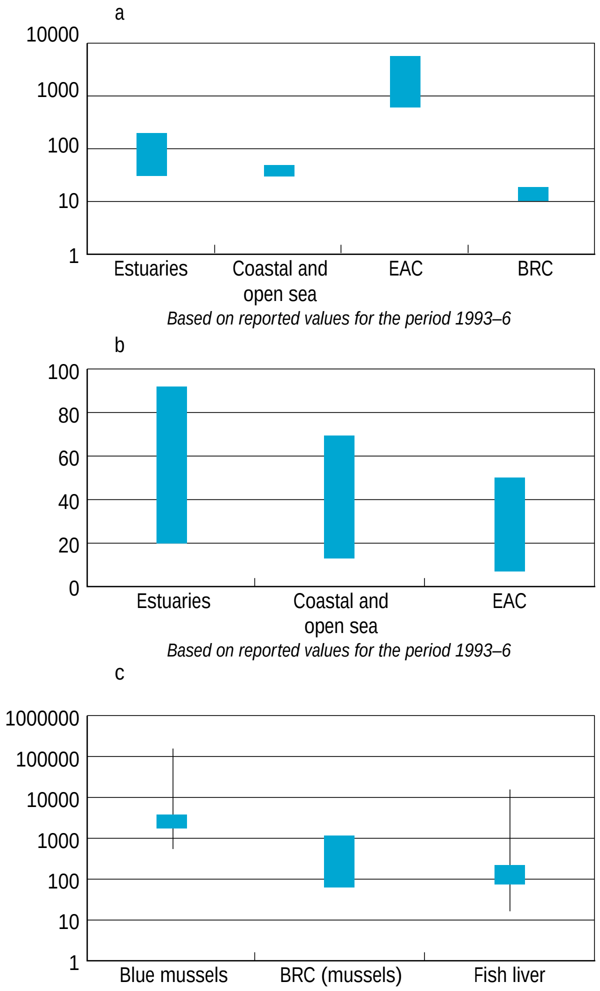


Figure 4.9 **Estimates of lead inputs to the North Sea (t/yr). Source: OSPAR (1998c).**



Atmospheric inputs are based on deposition measurements at coastal stations and calculated for an area of 525 000 km^2. Lower and higher estimates are reported for total waterborne inputs (riverine inputs + direct discharges).

Figure 4.10 **Lead concentrations: (a) in water (ng/l). Concentration ranges, EAC (firm); (b) in sediments (mg/kg). Concentration ranges and EAC (provisional); (c) in biota (ng/g dw). Concentration ranges and upper and lower quartiles. Source: OSPAR (2000).**



Based on 158 median yearly values for the period 1993–6. The bar indicates the data range and the box the data between the 25 and 75 percentile. The BRC range is also shown as a box.

the Wadden Sea, lead levels decreased by about 10% between 1988 and 1993 (Bakker *et al*., 1996).

Concentrations in biota

Most of the time series analysed showed no significant trend, except downward linear trends observed in blue mussels from Germany (Borkum), the Belgian coast, the Dogger Bank and Norway (Sørfjord). In the Belgian coastal area, a decrease in lead has been noticed in benthic organisms found in dredged spoil disposal sites.

Reference to EAC and BRC

Dissolved lead concentrations in seawater and estuaries were higher than the BRC, but all below the lower EAC. The BRC was exceeded by a factor 2 in the north-east area off the English coast and in the Forth estuary. The south-east area off the English coast and the Channel were just above the BRC. Dissolved lead concentrations in the Scheldt estuary exceeded background values by a factor of 10 (upstream) – 2.5 (near the mouth).

In sediments of the Belgian coastal zone, the upper EAC limits were not exceeded, but lower limits were exceeded at four sites, including two dredged spoil disposal sites. In the Scheldt estuary, enrichment factors in sediments varied from 1.4 – 24 with a median value of 2.4 (Vyncke *et al*., 1997).

For blue mussels, 27 of 31 time series were above the BRC. The data sets for the Seine area were up to five times higher than the BRC. The German coastal data sets were just above the BRC, with the exception of one location in the German Bight exceeding the BRC by a factor of 4. The Western Scheldt and Ems-Dollard were above the BRC by a factor of 3 and 4 respectively. In Norway, a number of locations were approximately ten times (Hardangerfjord) and up to forty times (Sørfjord) higher than the BRC. The Swedish Fladen and Väderöarna sites were just above the BRC.

4.4.5 Copper (Cu)

Sources and input estimates

Waterborne inputs did not show a clear trend between 1990 and 1996 *(Figure 4.11)*. *Table 4.13* gives examples of the proportion of riverine and direct inputs, and the difference between lower and upper estimates in two different years. This might be explained by the relative importance of diffuse sources.

The decrease of atmospheric emissions has been less pronounced for copper than for other heavy metals (Table 4.9.). Deposition data from coastal stations have not been assessed by OSPAR in recent years, but model calculations give an estimate of 56 t/yr reaching the Greater North Sea, 96% originating from OSPAR Contracting Parties (Van Pul *et al*., 1998). This is, however, a minor contribution when compared to the waterborne inputs.

Copper concentration ranges are summarised in *Figure 4.12*.

Concentrations in water

Very little information concerning the concentration of copper in water has been made available for the period under investigation. On the other hand, copper is a micro-nutrient, and its concentration is influenced by biological activity in the water column.

Figure 4.11 **Total waterborne copper input to the Greater North Sea (t/yr). Source of data: lower estimates of riverine and direct inputs in OSPAR (1998c).**

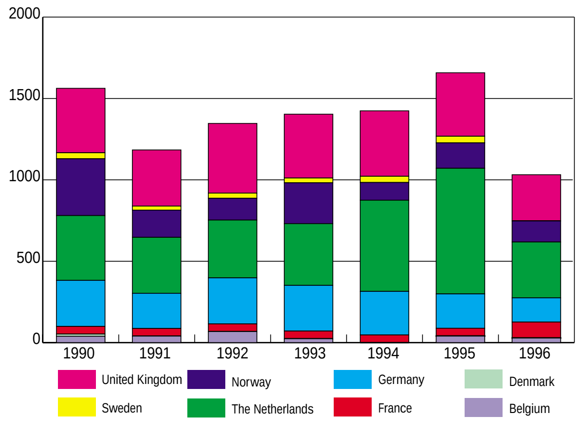


Table 4.13 Riverine and direct inputs of copper to the Greater North Sea in 1990 and 1996. Source of data: OSPAR (1998c).

	Riverine inputs (t)		Direct inputs (t)	
	1990	1996	1990	1996
Belgium	39* 51**	28* 61**	n.i.	0.002
Denmark	10.5	n.i.	3.13	1.17
France	47* 49**	97	n.i.	n.i.
Germany	282§	147§	0.9* 1.9**	2.2* 3.0**
Netherlands	390§	340§	8.3	2.6
Norway	270	94	79	35
Sweden	36.7	22.1	0.48	2.1
United Kingdom	187* 202**	171*	209* 219**	113
TOTAL‡				
Lower estimate*	1 200*	900*	300*	160*
Upper estimate**	1 300	1 000	310**	160*

§ Including loads from countries upstream.
‡ Total rounded to two significant digits.
* Lower estimate: for concentrations less than the detection limit, the value '0' was used when calculating loads.
** Upper estimate: for concentrations less than the detection limit, the value of the detection limit was used when calculating loads.
n.i. no information

Note: Some 1990 data updated by OSPAR may differ from those reported in the 1993 QSR.

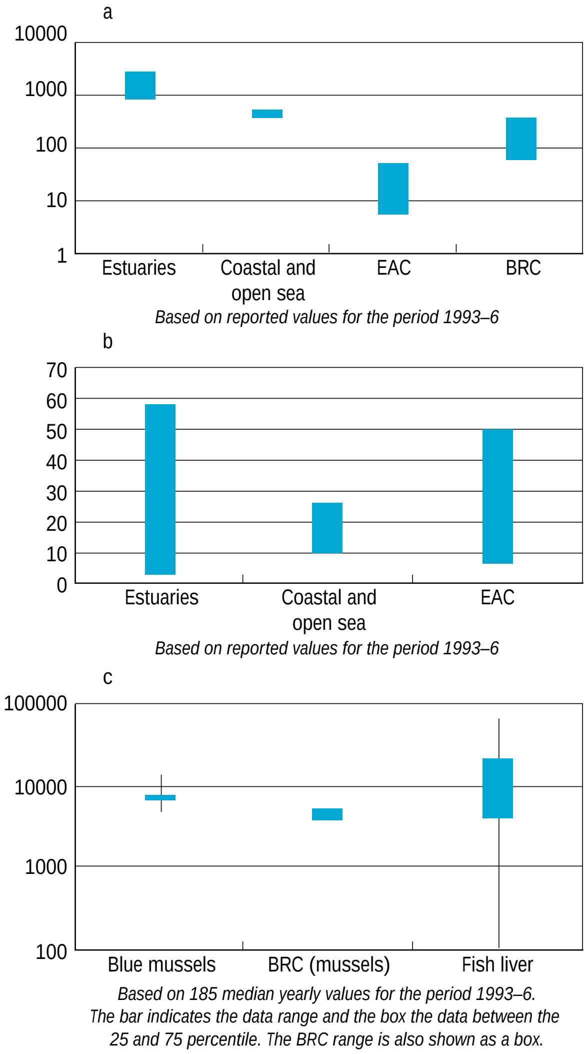
Concentrations in sediments

In the Dutch coastal zone, copper concentrations decreased between 1981 and 1996 in the areas north (40%) and south (30%) of the Rhine/Meuse mouth, and in the offshore area (35%) (Laane *et al*., 1998). Major decreases were noticed for sediments along the Belgian coast, including in the dredged spoil dumping zone, with concentrations dropping by 65% between 1990 and 1996. In the Wadden Sea, a reduction of about 20% was observed in 1993 as compared to 1988 (Bakker *et al*., 1996).

Concentrations in biota

Trend analysis conducted on 71 time series of up to 15

Figure 4.12 **Copper concentrations: (a) in water (ng/l). Concentration ranges, EAC (firm); (b) in sediments (mg/kg). Concentration ranges and EAC (provisional); (c) in biota (ng/g dw). Concentration ranges and upper and lower quartiles. Source: OSPAR (2000).**



years duration in mussel and fish tissue (OSPAR, 2000) revealed eight linear downward trends: in Denmark (Hvide Sande), Germany (Jade Bay, outer Weser, Borkum), The Netherlands (Terschelling) and Norway (Oslofjord, Sande and Sørfjord). Sites in the Elbe estuary showed decreasing patterns, a trend that is attributed to the decline of chemical industries in the former GDR. Nevertheless, concentrations are still high, possibly due to releases from the Czech Republic. Two upward trends were detected, in France and Norway.

Reference to EAC and BRC

Dissolved copper concentrations in seawater were generally higher than the upper EAC. However, copper is an essential element. The toxicological value is slightly higher than the value needed to avoid biological deficiencies. In these cases, the EAC tends to be lower than the BRC, and is therefore less useful as a quality criterion. Discussion is ongoing internationally to solve this problem. Concentrations were in the range of the BRC along the north-east coast of England and in the Channel, and just above the BRC in the south-eastern area off the English coast. The BRC was exceeded by a factor 2 – 5 in the Tay estuary and 3 – 7 times in the Forth estuary. In the Scheldt estuary, dissolved Cu concentration exceeded background values by a factor 2 – 4.

In sediments of the Belgian coastal zone, the EAC was reached at only one dredged spoil disposal site. In the Scheldt estuary, sediments were slightly enriched.

Comparing the mean concentrations in blue mussel with the BRC, 53 of 61 blue mussel data sets were above the BRC, but because copper is known to be bio-regulated by blue mussels, interpretation is more difficult for this species.

4.5 Persistent organic contaminants

4.5.1 Organo-tin compounds

Sources and input estimates

Tributyl tin (TBT) is widely used as an anti-fouling agent in paint for ships. Vessels with a length of more than 25 m (its use has been forbidden for smaller vessels since 1990) are the major input source. Apart from harbours, dry docks and TBT-related industrial effluents are important sources. Denmark estimates their TBT input for 1997 at 0.6 – 4.9 tonnes (1/3 of the estimated use) while the Norwegian input ranged between 17.8 and 57.3 t/yr over the period 1985–95. The UK estimates annual TBT inputs to be 6 t/yr (OSPAR, 1997c).

Fluxes and transport routes

Few laboratories are able to measure the low concentrations of TBT and its degradation products (monobutyltin (MBT) and dibutyltin (DBT), often present in comparable concentrations, phenyl-tin and methyl-tin).

Concentrations in water

TBT concentrations in offshore waters are generally less than 1 ng/l (expressed as TBT), whereas values of the order of 100 ng/l are found in frequently used waterways. Marina areas are highly contaminated with TBT due to historic inputs, but in countries where effective regulations have been introduced, concentrations have substantially decreased in the past decade. In addition to statutory controls, the rate of leaching of TBT from large vessels has been reduced by the use of co-polymer rather than free-association paints.

Only a very limited amount of data is available from special surveys (OSPAR 1997i). In water, the highest concentrations have been observed in Germany (0.243 µg/l (Dornumer Siel) to 0.35 µg/l (Bremerhaven) in harbours), the Netherlands (up to 0.14 µg/l (Rotterdam)), France (in marinas) and Denmark (up to 0.12 µg/l in harbours).

Concentrations in sediment

In sediments near sources values up to 16.9 mg/kg have been observed in Denmark. Concentrations in UK samples ranged from less than 0.002 mg/kg at offshore sites to over 10 mg/kg in some harbour areas. In Norway all sediment values ranged from less than 0.01 – 1 mg/kg. In Belgium, values up to 0.081 mg/kg were found in the Scheldt. Concentrations in the range 0.0036 – 0.046 mg/kg were reported in the Dutch Western Scheldt and from 0.050 – 0.070 mg/kg in the harbour of Rotterdam.

Concentrations in biota

In biota, values from Norway are up to 3 mg/kg in blue mussels and 0.43 mg/kg in dog whelks (*Nucella lapillus*) (OSPAR, 1997c).

A number of studies point out that, even in remote areas with low concentrations of TBT in the water, accumulation occurs in the liver and kidneys of seabirds.

Reference to EAC and BRC

Since the EACs are close to or even below the detection limit of most laboratories, particular concern should be attributed to ambient concentrations, and it is impossible to judge even the lowest observed concentrations. Generally, offshore water and sediments show no detectable concentrations, but concentrations of up to 3 500, 1 200 and 300 times the EAC for water have been recorded in harbours, marinas and rivers respectively.

For sediments, the measured concentrations are up to 30 million times the upper EAC in harbours, up to 1600 times the upper EAC in rivers and less than 30 times the upper EAC in frequently used offshore waterways. In mussels, values are usually lower than the upper EAC in the coastal zone, but up to 300 times the EAC in harbours.

4.5.2 Polychlorinated biphenyls (PCBs)

The term ‘PCBs’ refers to analyses conducted on a total basis, whereas the individual congeners are referred to as ‘CB’ (chlorinated biphenyl) followed by the IUPAC number. Among the many CB congeners it is possible to measure, the sum of 7 congeners ($\sum PCB_7$: CBs 28, 52, 101, 118, 138, 153 and 180) is usually reported to OSPAR. CB153 is often used as a CB representative of all the others, and in biota it constitutes around 10% of the total amount.

Sources and input estimates

In coastal waters, waterborne inputs of PCBs are dominant, whereas atmospheric deposition is more important in the open sea. The atmospheric input by wet deposition to the OSPAR Convention area is estimated to be 3 – 7 t/yr for the period 1992–4 (dry deposition is not known) (OSPAR, 1997d). The main source is electrical equipment (OSPAR, 1998f). More than 90% of the total release of PCBs occurred before 1980. The estimated inputs to the Greater North Sea by direct and riverine inputs ranged from 530 – 1 500 kg/yr between 1990 and 1996 ***(Table 4.14)***.

Fluxes and transport routes of PCBs

The semi-volatile nature of PCBs is the reason for their effective transport over long distances in the atmosphere. No data are available about the fluxes to the North Sea area. Total deposition fluxes for PCBs in the Skagerrak were estimated to be 2 – 6 x 10^{-3} µg/m^2/day (OSPAR, 1997d). In water, PCBs are mainly adsorbed to particles and thus transported by materials in suspension.

Concentrations in water

Due to their low solubility, PCB concentrations in water are usually extremely low and hence difficult to detect. From a 1990 survey in Scottish waters (SOAEFD, 1996), it was concluded that values at most places were less than 1 ng/l for the sum of all the congeners. However in the Elbe plume, CB 153 concentrations were found up to 30 ng/l. At other locations in the German Bight, concentrations were below 10 ng/l.

Concentrations in sediments

Individual CB congeners are commonly detected in sediments but levels are generally low in the western North Sea (less than 2 µg/kg), with the highest levels measured in the Forth estuary ($\sum PCB_7$ 6.8 – 11.3 µg/kg). Concentrations in the open sea were less than 1 µg/kg.

Relatively high concentrations were measured in the Ems, Elbe and Scheldt estuaries (Kallo, $\sum PCB_7$ 382 µg/kg in 1993; OSPAR, 1998g). $\sum PCB_7$ concentrations greater than 20 µg/kg were found in the Dutch coastal zone. The concentrations of PCBs dropped by 70% close to the Rhine/Meuse mouth and by 80% outside of the plume in the period 1986–96.

Concentrations in biota

Concentrations of CBs in dab liver off UK coasts were found to be less than 0.1 µg/kg ww, except in the Thames estuary ($\sum PCB_7$: 0.19 µg/kg ww in liver) and the Forth estuary ($\sum PCB_7$: 0.355 µg/kg ww). These are the highest values for the western North Sea. High levels of non-ortho and mono-ortho PCBs in cod liver have resulted in advice against consumption of liver from the inner part of several Norwegian fjords (Oslofjord, Drammensfjord, Sandefjordsfjord, Kristiansandsfjord and fjords around

Table 4.14 Riverine inputs (kg) and direct discharges (kg) to the maritime area by country. Source: OSPAR (1990–95 data: 1998b; 1996 data: 1998a).

Country	Way	1990		1991		1992		1993	
		γ-HCH	ΣPCB	γ-HCH	ΣPCB	γ-HCH	ΣPCB	γ-HCH	ΣPCB
Belgium	Direct	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
	Riverine	102	31	100–122	22–28	77–88	14–40	62–98	3.5–419
Denmark	Direct	0–30.3	0–30.3	0–30.3	0–30.3	0–30.3	0–30.3	0–30.3	0–30.3
	Riverine	0–30.3	0–30.3	0–30.3	0–30.3	0–30.3	0–30.3	0–30.3	0–30.3
France	Direct	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
	Riverine	175	171–242	175	171–242	175	171–242	175	171–242
Germany	Direct	4.8	0.0–1.0	4.8	0.08–1.6	0.0–0.3	0.04–1.10	0.0–0.3	0.04–1.10
	Riverine	342	68–218	183	3.2–174	207–209	6–80	193–194	20–87
Netherlands	Direct	5.7	5.7	5.0	0.8	3.9	0.0–0.9	3.9	n.i.
	Riverine	11	150	2.4	130	6.6	96	360	130
Norway	Direct	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
	Riverine	420	74–530	216	1.5–40	70	0.04–41	61	0.1–21
Sweden							n.i.		
UK	Direct	150–152	77–142	128–154	2.5–101	103–104	2.1–10.0	110–111	0.7–62
	Riverine	147–234	31–1800	224–351	4.1–690	142–239	10–360	245–298	13–710

n.i. no information

Bergen). High levels were also observed in blue mussel samples at Borkum and Mellum (0.710 mg/kg dw). However, there is no information on time trends since most available data has not been quality assured.

Reference to EAC and BRC

For blue mussel samples collected along the coast of Norway, mean concentrations were generally about twice the BRC. The high value observed in dab near Haakonsvern exceeded the BRCs by a factor of 20. The mean concentrations of the CB153 congener in blue mussel tissue from the coasts of Germany and Belgium are on average about twelve times the BRC values. ΣPCB_7 levels off the German coast vary from 1.5 – 15 times the BRC, meaning that the EAC was exceeded by a factor of 2 – 3. Along the coast of Norway, the mean concentrations of CB153 were about twice as high as the BRCs for blue mussels, in all but a few sites.

4.5.3 Polycyclic aromatic hydrocarbons (PAHs)

In some cases only 6 PAHs (defined by Borneff) have been measured, whereas in other cases a more extended series of PAHs (such as the 16 of EPA, which incorporate the 9 PAH compounds agreed by OSPAR, see *Table 4.15*) have been reported as 'Total PAHs'. As a result, it is difficult to compare data from different sources.

So far, little is known about the concentrations of the degradation products of PAHs in the North Sea area, like their sulphur-, hydroxylated- and nitro-analogues, which often have a greater persistence than their precursors (Bakker *et al*., 1996).

Sources and input estimates/trends

Annual atmospheric emissions of PAHs from mainly land based activities in North Sea riparian states, were estimated to be of the order of 7 000 t in 1990 *(Table 4.16)*. This value is an underestimate because harmonised data were not available for all of the main activities. Other emissions occur at sea, from shipping and from the offshore oil and gas industry. The respective proportions of emissions of PAHs deposited on sea and on land are unknown.

Waterborne inputs of PAHs enter the North Sea via rivers and direct discharges from land. Coal tar containing coating systems are an important source. Reliable estimates are not available, but an indication of the relative importance of waterborne PAHs is given by the concentrations found in sediments (see below). Spillage and operational discharges of oil from shipping and the offshore oil and gas sector also contribute a direct input of PAHs into the marine environment. *Table 4.20* gives the inputs of PAHs from offshore oil and gas installations in

1994		1995		1996	
γ-HCH	ΣPCB	γ-HCH	ΣPCB	γ-HCH	ΣPCB
n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
52–97	3.5–444	54–57	9.2–83	n.i.	n.i.
0–30.3	0–30.3	0–30.3	0–30.3	n.i.	n.i.
0–30.3	0–30.3	0–30.3	0–30.3	n.i.	n.i.
n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
175	171–242	175	171–242	120	95
0.0–0.3	0.01–1.00	0.4	0.05–1.10	0.04–0.05	0.02–1.00
250–272	40–150	291	58–230	234–243	55–200
3.9	0.9	3.9	0.9	n.i.	n.i.
150–310	300	352–385	470	300	200
n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
61	36–54	70	0.1–25	48	0.1–16.8
85–86	0.01–60	90–92	0.3–71	61–66	0.4–140
196–265	8.4–697	154–251	0.3–646	96–140	30.0–410

Table 4.15 Overview of PAH compounds.

PAH	Borneff	EPA	OSPAR
Indeno[1,2,3-*cd*]pyrene	●	●	●
Benzo[*b*]fluoranthene	●	●	
Benzo[*k*]fluoranthene	●	●	
Benzo[*a*]pyrene	●	●	●
Benzo[*ghi*]perylene	●	●	●
Fluoranthene	●	●	●
Phenanthrene		●	●
Anthracene		●	●
Pyrene		●	●
Naphtalene		●	
Acenaphthylene		●	
Benz[*a*]anthracene		●	●
Chrysene		●	●
Acenaphthene		●	
Dibenz[*a*,*h*]anthracene		●	
Fluorene		●	

the Norwegian, Dutch and Danish sectors as 28 t in 1996. Assuming that there is a correlation between the discharges of PAHs and produced water, this indicates that the waterborne contribution of PAHs from all North Sea offshore installations would be of the order 100 t/yr.

Concentrations in water

Higher concentrations were generally found in coastal and estuarine samples with total PAH concentrations up to 8.5 µg/l. Total PAH concentrations higher than 1 µg/l were found in the estuaries of the rivers Tees, Humber, Great Ouse, and Thames. On the east coast of England, of 39 samples taken in 1993 at offshore locations only one (off the river Tyne) showed an elevated concentration of naphthalene (0.263 µg/l). In the German Bight, the concentration of the sum of 7 PAHs was between 0.0018 and 0.09 µg/l.

Concentrations in sediments

The DIFFCHEM survey (OSPAR, 1997a), which described the presence of PAHs in 22 estuaries in western Europe, revealed that fluoranthene was the most prominent PAH (values ranged between 33.9 and 1 022 mg/kg dw), but benzo[*b*]fluoranthene, pyrene and benzo[*e*]pyrene were also abundant. Values for the sum of all PAHs were between 0.218 mg/kg (Wadden Sea) and 6.08 mg/kg (Scheldt estuary). In a pilot study (River Glomma, Norway) the total concentration of 21 PAHs was between 0.073 and 0.370 mg/kg, while the concentration of the carcino-

Table 4.16 Main sources and total annual emissions of PAH to air in 1990 for North Sea countries.

Country	Main sources (the two major sources are given) (*)	Total annual emissions of PAH (t/yr)	Reference
Belgium	Wood preservation, road transport	818	OSPAR (1997k)
Denmark	Wood preservation, stationary combustion/road transport	76.7	van den Hout (1993)
France	Stationary combustion/road transport	3479	OSPAR (1997k)
Germany	Stationary combustion/road transport	420	van den Hout (1993), OSPAR (1997k)
Netherlands	Solvent use (incl. wood preservation), stationary combustion	184	OSPAR (1997k)
Norway	Aluminium industry, wood preservation	140	van den Hout (1993)
Sweden	Stationary combustion/road transport	282	OSPAR (1997k)
UK	Wood preservation, stationary combustion	1437	van den Hout (1993), OSPAR (1997k)

(*) Wood preservation: assumed to include both production and use of creosote treated timber.
Stationary combustion: including both diffuse and point sources.
Road transport: not including emissions from road construction.

genic congeners was between 0.032 and 0.110 mg/kg (OSPAR, 1998h). Data from the Dutch coastal zone and from the whole Wadden Sea, showed no significant reduction in PAH levels between 1986 and 1996 (Laane *et al*., 1998). However in the Wadden Sea, an increase was found at 40% of the locations.

Offshore, the most prominent PAHs of those measured were naphthalene, phenanthrene, chrysene and benzo[*a*]pyrene. In Scottish marine sediments, total PAH concentrations were between 0.028 and 0.20 mg/kg.

Concentrations in biota

In the period 1988–95, in the Scheldt estuary, concentrations of fluoranthene and pyrene in blue mussel diminished, while benzo[*a*]anthracene concentrations did not change significantly. In the Ems-Dollard, no change in pyrene, benzo[*a*]pyrene or chrysene concentrations in blue mussel were noticed, but benzo[*a*]anthracene levels decreased.

Reference to EAC and BRC

An intermediate value of the EAC for pyrene in estuarine sediments of 0.1 mg/kg, within the range mentioned in *Table 4.7*, was exceeded at most locations, whereas for the other PAHs, the situation is more favourable, except in the estuaries of the Seine, Humber and Scheldt rivers.

Background values for water and biota are still under discussion. From the data it could be concluded that concentrations of some PAHs (e.g. fluoranthene, pyrene, benzo[*a*]anthracene, chrysene and benzo[*a*]pyrene) in the blue mussel at two sites in the Netherlands are decreasing and below the available EACs.

4.5.4 Other persistent organic compounds

Most persistent organic compounds other than PCBs and PAHs, are not systematically measured. Under CAMP, for example, only two organic substances (α-HCH and γ-HCH (hexachlorocyclohexane)) are to be measured monthly in rainwater on a mandatory basis. As a consequence, relatively few data (in time and space) are available for these compounds, and few EACs and BRCs have been established. Therefore, more information, covering the whole of the Greater North Sea and over a prolonged time is needed.

Estimated atmospheric emissions (1995) of eight organic substances and estimated reductions from 1985–95 are given in *Table 4.17*.

Dioxins and dibenzofurans

Data reflecting the degree of sediment contamination by these compounds are scarce, although one Norwegian study gives some baseline information (NIVA, 1995). Extremely high levels of PCDF/PCDDs in sediments were found in Frierfjorden in 1989, near a magnesium works (0.004 – 0.018 mg/kg TEQ), and in the Kristiansandfjord (0.002 mg/kg TEQ). Even off the south-eastern open sea coast of Norway, some 20 km from the waste outfall, the local background was exceeded 5 – 100 times. In the Dutch coastal zone, highest concentrations of PCDDs and PCDFs have been measured in the sediments of the Scheldt and Rhine estuaries (Evers *et al*., 1997). The absolute concentrations of PCDD and PCDF did not change much between 1985 and 1994 in these areas.

The presence of dioxins in the tissue of several seafood species at some Norwegian locations reflects the high values in sediments. Dioxin levels in crab hepatopancreas were 708 ng TEQ/kg ww (1993) at Frierfjorden, the same location where high dioxin levels in the sediment were found. Also in the nearby Breviksfjord, high levels were observed in the same matrix (481 ng TEQ/kg ww). Mixed soft bottom fauna also showed high levels at the same locations (Frierfjorden: 312 ng TEQ/kg ww; Breviksfjord: 64 ng TEQ/kg ww). Finally, in Frierfjorden, the

Table 4.17 Estimated atmospheric emissions of eight organic substances in 1995 and estimated percent reductions from 1985 to 1995. Source: 4NSC (1995).

Substance	Belgium		Denmark		France		Germany[11]	
	1995	%	1995	%	1995	%	1995	%
Lindane	-	>50[2]	0	100	-	-	-	-
Pentachlorophenol	0[1]	100	0	≈ 100	-	-	0	100
Hexachlorobenzene	-	-	0	100	-	-	<0.09	-
Carbontetrachloride	29.6	90	0	≈ 100	-	-	0	100
Trichloroethylene	1300	61	1200[3]	40-60	-	-	<14 000	<66
Tetrachlorethylene	2390	60	300[3]	50/70	-	-	<11 693	<83
Trichlorobenzene	3[12]	0	0	≈ 100	-	-	-	-
Trichloroethane	0[13]	100	400[3]	25/100	-	-	<26 000	100

1: No use in 1995. 2: Used tonnage. 3: Emissions in 1993/94 and with estimated reductions in 1985/1985-99. 4: No commercial use. The figure given concerns one industrial plant. There is no estimate for 1985, but the discharges of HCB are nearly eliminated and atmospheric emissions of total chloroorganic substances are greatly reduced. It is therefore assumed that the 50% target is achieved. 5: Discontinued 1 January 1996. The figure includes emissions of carbontetrachloride as a by-product associated with the production of chlorinated monomeres. 6: The figures are based on used quantities. The atmospheric emissions within the Swedish part of the catchment area can be anticipated to be about 20% of the figures.

stomach content of cod again yielded a high value of 208 ng TEQ/kg ww (1994 values). There are also restrictions on consumption of seafood in this area due to dioxins.

Toxaphene

The pesticide toxaphene has been found in German estuaries and related plumes. Very high toxaphene concentrations have been found in the blubber of dolphins from the central North Sea (19 mg/kg) (ICES, 1997).

Brominated flame retardants (BFRs)

Brominated compounds (PBBs and PBDEs) and chlorinated paraffins (CPs) are used as flame retardants and as additives in a number of products. Levels for DeBDE in sediments at various locations in the North Sea ranged from less than 1 x 10^{-4} to 1.7 mg/kg. High levels were also found in the river Scheldt (0.2 mg/kg) and off the Humber (0.04 mg/kg). Levels for other BFRs and CPs were less than 0.01 mg/kg (OSPAR, 1997a).

In the tissue of different fish species collected off the Dutch coast, concentrations of these compounds from less than 5 x 10^{-6} mg/kg dw up to 5.5 mg/kg (for BDE-47) were observed. (Boon *et al*., 1997).

Concentrations of CPs in river sediments were far lower than those of the BFRs measured in the DIFFCHEM Survey (OSPAR, 1997a), with the highest levels found in the river Scheldt (0.006 mg/kg). High concentrations of BFRs have been demonstrated in the blubber of marine mammals.

Hexachlorocyclohexanes (HCHs)

HCHs are a group of chlorinated pesticides. Application of γ-HCH (lindane) is restricted. At some locations in the Skagerrak, there was a correlation between the deposition of HCHs and the amount of precipitation. Deposition fluxes for the HCHs were up to 60 ng/m^2day.

Concentrations of HCHs in water are presented in *Figures 4.13* and *4.14*. Typically, values for α-HCH were lower than for γ-HCH. As was already reported in the 1993 QSR, a clear gradient is observed for γ-HCH, with low concentrations in the northern North Sea and higher levels in the southern North Sea.

Data on HCHs in sediments are only available for the Scheldt estuary and for the English coast. Values for α-HCH were low at the various locations (less than 0.001 mg/kg), while the concentration of γ-HCH was relatively high in the Scheldt estuary (up to 0.004 mg/kg in 1992). In the Scheldt estuary, an upstream gradient was noticed for α-HCH (period 1990–5).

Concentrations of α-HCH and γ-HCH in fish liver and mussel tissue decreased between 1990 and 1995, especially in relatively polluted regions of river estuaries, fjords and near coastal zones. In contrast, a significant upward trend was observed over the same period in dab muscle collected from Lista (Norway).

Highest values for γ-HCH exceeded EAC levels in mussels from the East Frisian Wadden Sea and at a site in the Scheldt estuary. No EACs or BRCs are available for α-HCH.

Hexachlorobenzene

Hexachlorobenzene (HCB) was found in the Forth estuary as a result of a known industrial discharge (0.009 µg/l). Comparison with former data showed that a significant reduction of HCB was observed, which corresponded to reduced effluent discharges.

Estuarine sediments are a source of HCB, which in addition to point source discharges may result in elevated concentrations in the water column. Concentrations of HCB in the Elbe estuary were around 0.003 µg/l, while in the German Bight a decrease was noticed (values less than 0.001 µg/l; Goerke and Weber, 1998). Results from

The Netherlands		Norway		Sweden[6]		Switzerland		United Kingdom[10]	
1995	%	1995	%	1995	%	1995	%	1995	%
≈ 0	>99	0	-	0	-	0	100	-	-
38	24	-	-	0	-	0	100	-	>50
0.002	98	0.13[4]	>50	0	-	0	100	-	>50
116	80	<2	>84/100[5]	1	>50[7]	-	>50	-	>50
972	52	320	58	2000	>50[8]	-	>50	-	-
1310	50	350	71	400	>50	-	>50	-	>50
0.43	45	0	-	0	-	-	80-90	-	>50
<2500	>51	200	87/100[5]	1	>50[9]	-	>50	-	>50

7: Banned for professional use 1993. 8: Banned for professional use from 1996. 9: Banned for professional use 1995. 10: Data are insufficient to determine specific reductions. However, where phase out or significant reductions in sales/use are known, anticipated reductions in inputs are indicated. 11: Data from the Federal Republic before its reunification. 12: The emissions are diffuse and too small to be considered as requiring priority attention. 13: Banned from 1 January 1996. Trichloroethane is expected to be replaced in some case by trichloroethylene.

Figure 4.13 **Geographical distribution of α-HCH concentrations in surface water (at a depth of 7m). Source: Theobald *et al*. (1996).**

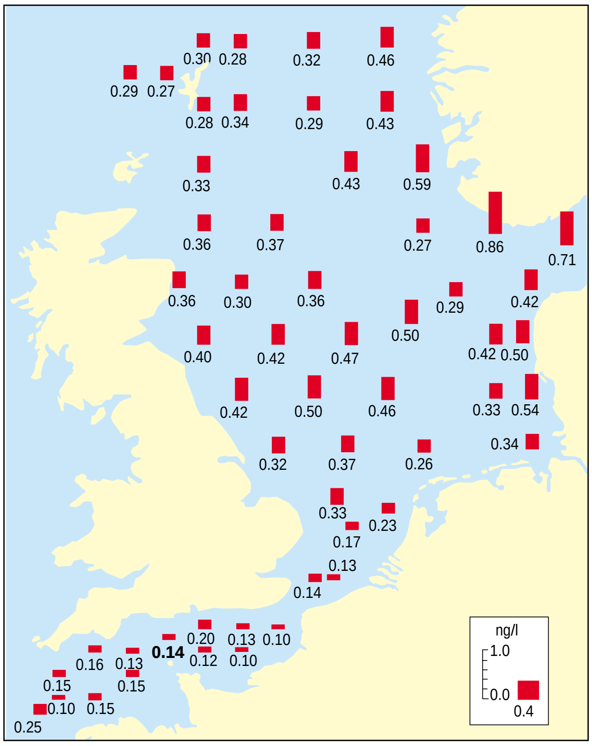
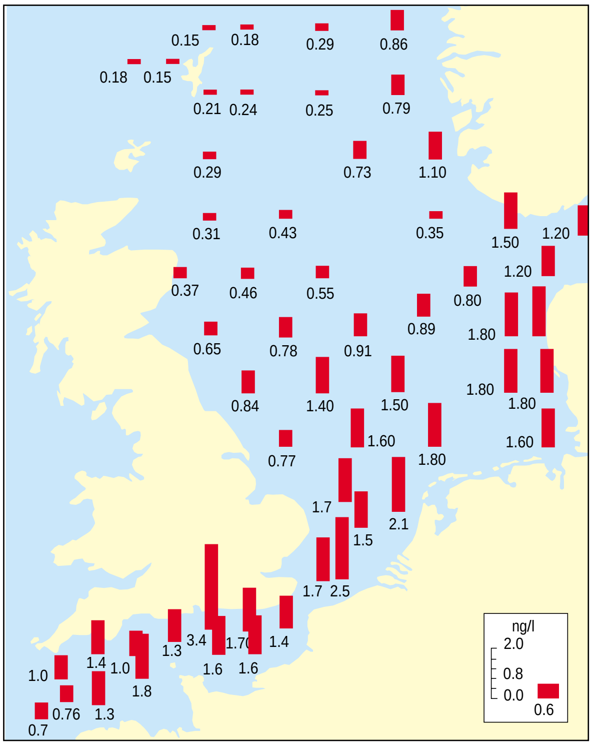


Figure 4.14 **Geographical distribution of γ-HCH concentrations in surface water (at a depth of 7m). Source: Theobald *et al*. (1996).**



other sites (e.g. in the Tay estuary) were below the detection limit.

In sediments, high concentrations were measured in the Forth estuary (3 – 130 µg/kg), with a rapid decrease in the coastal zone (2 to 4 µg/kg) and further offshore (less than 0.2 µg/kg). Concentrations in the Forth were two orders of magnitude higher than elsewhere in Scotland, reflecting well known historic inputs. Concentrations in the Scheldt estuary were comparable (0.3 – 5.3 µg/kg).

Between 1988 and 1995, concentrations of HCB, determined in fish liver and blue mussel, decreased at most locations (Weser, Elbe, Dutch coastal zone, Ems estuary, Oslofjord, Kattegat and Southern Bight). A good correlation was observed between high HCB levels in sediments and levels in biota, for example in the Forth estuary (e.g. in dab and flounder). EACs or BRCs are not available for HCB.

DDT and analogues

Concentrations in sediments greater than 1 µg/kg for total DDT (the sum of DDE, DDD and DDT) were detected off the Tyne (1.2 µg/kg) and in the estuaries of the Forth (3 – 12 µg/kg) and Scheldt (1 – 13 µg/kg).

Levels of DDT in dab liver from the British coastal zone and offshore regions were less than 0.1 mg/kg ww The highest values were observed in 1993 in the Forth estuary (0.07 mg/kg ww) and in the Humber (0.09 mg/kg ww). In these samples, DDT was only a small fraction of the ‘total DDT’ concentration, indicating that inputs were not of recent origin. Downward trends for DDT in cod and plaice liver were evident in time series from the Southern Bight and in herring muscle from Kattegat (Fladen). At other locations, levels were below the detection limits.

Mean values for p,p’-DDE in the period 1990–5, varied from less than 10 – 630 µg/kg dw in blue mussel and from 32 – 1000 µg/kg dw in fish.

For p,p’-DDT, no EACs have been established, while for p,p’-DDE, EACs were available for mussel and fish. At only one location (Sørfjord), the EAC was exceeded by a factor 1.5. There were no BRCs either for p,p’-DDE or for p,p’-DDT.

Dieldrin, simazine, atrazine

The herbicides simazine and atrazine were detected in the waters of the Wear (0.027 µg/l atrazine), Humber, Tees and Tyne (up to 0.006 µg/l simazine) and in the German Bight. Concentrations were, however, low at most locations and generally decreased offshore (e.g. dieldrin concentrations were all below 0.15 ng/l offshore).

In sediments from the Scheldt estuary (Vyncke *et al*., 1997) and from UK coasts and estuaries, the (banned) pesticide dieldrin was detected at all the sites that were sampled, albeit at generally low concentrations. The highest concentrations were found in the Forth and Scheldt estuaries (0.001 – 0.002 mg/kg). The difference between estuarine and offshore sites was small.

Elevated concentrations of dieldrin in dab liver were found in the Thames estuary (0.049 mg/kg ww), in the outer Moray Firth (0.072 mg/kg ww) and in the Forth estuary (0.023 mg/kg ww). All UK sites showed downward trends in all tissues. A significant downward trend was noticed for dieldrin in blue mussel and in fish tissue (Scheldt estuary, Ems-Dollard estuary).

EACs were only available for dieldrin. Concentrations of dieldrin in different biota were all far below EAC values.

Other compounds

Only few studies on other compounds were available. Such compounds are reported below. When present in marine waters these substances attained concentrations equal to or even higher than those for commonly measured contaminants such as HCHs, PCBs or HCB.

It was calculated that the influx to the Greater North Sea of biogenic halocarbons, like tetrachlorocarbon, chlorinated ethenes and tribromomethane, via the Skagerrak is 40 t/yr (Abrahamsson and Ekdahl, 1996).

Benzothiazoles (Bester *et al*., 1997) were measured in estuarine and marine waters at concentrations, ranging from 0.04 – 1.37 µg/l for methylthiobenzo-thiazole in the North Sea, while 55 µg/l were found in the river Elbe. The values for benzothiazole vary from 0.25 – 2.7 µg/l.

HHCB (trade name galaxolide®) and AHTN (trade name tonalid®), which are musk fragrances from laundry detergents and cosmetics (as replacements for nitroaromatic musks), enter the aquatic environment via sewage treatment plants. These compounds bioaccumulate in marine organisms. Musk fragrances are considered to be endocrine disrupters, although this has not been proved for HHCB and AHTN. In the period 1990–5, HHCB concentrations ranged from 0.09 – 4.8 µg/l in the German Bight and up to 95 µg/l in the Elbe estuary, while for AHTN they varied from 0.08 – 2.6 µg/l, and up to 67 µg/l in the river Elbe. Whilst AHTN concentrations remained relatively constant, HHCB showed an upward trend at some stations.

Concentrations of 2,5-dichloroaniline from upstream industrial activity, were up to 1 µg/l in the Elbe estuary. In the German Bight they ranged from less than 0.01 – 0.65 µg/l (Bester *et al*., 1998).

High levels of octylphenol and nonylphenol ethoxylates (OPE and NPE, cleaning agents with a suspected endocrine disruptive capacity) were found in sediments in the river Scheldt (20 µg/kg and 300 µg/kg respectively) and in the Elbe (5.6 µg/kg and 107 µg/kg respectively). In the UK, the OPE levels varied between less than 0.1 µg/kg and 15 µg/kg and the NPE levels between 23 and 44 µg/kg.

A remarkably high content of polychlorinated terphenyls (PCTs) was found in the livers of Wadden Sea eider ducks (*Somateria mollissima*) (Arochlor A5442 content 3.4 – 4.0 mg/kg fat). In the same area, in different marine wildlife samples, chlordane concentrations of 0.006 – 1.273 mg/kg ww were found (Boon *et al*., 1998).

4.6. **Multiple chemical inputs**

4.6.1 Mariculture

Anti-microbial and anti-parasite compounds are the two main groups of chemicals that may be found in measurable concentrations in sediments around fish farms. The list of anti-microbial compounds (oxytetracycline, oxolinic acid, sulphonamides, penicillin, and other therapeutants) is undergoing continuous change as new compounds are brought forward for licensing. The organo-phosphorous compounds dichlorvos and azamethiphos are authorised for use against parasites, and, recently, hydrogen peroxide treatment has been introduced.

Most antibiotics are administered as feed additives and enter the sea via waste feed and faeces. Despite the uncertainties in some estimates, there is a consistent pattern of reduction in the use of anti-microbial agents in Norway, Ireland and Scotland, even though the production of fish has increased considerably. The total amount of antibacterial agents reported for Norwegian mariculture in 1995 was 3.2 t (26.8 t in 1991) and the same trend is noticed for dichlorvos (395 kg used in Norway in 1995, down from 3 400 kg in 1990). More than 1 500 tonnes of hydrogen peroxide was used in 1995.

Most anti-microbial compounds readily associate with particles. Studies have shown that the concentrations of oxytetracycline in sediments are between 0.1 and 10 mg/kg near the farm cages. The residues are confined to a very small area (about twice the area of the cages) and to the top 10 cm layer of the sediments (Kerry *et al*., 1995, 1996). Reported half-lives of these pharmaceuticals vary from a few days to six months (Samuelsen *et al*., 1992). By contrast, dichlorvos is fairly soluble in seawater and is not found in marine sediments. Hydrogen peroxide degrades rather rapidly in the sea.

4.6.2 Offshore chemicals (other than oil)

Sources of contaminants arising from the offshore oil and gas industry are drilling muds and cuttings, produced water and spills. Other substances apart from oil are involved (*Tables 4.18* and *4.19*).

An estimate of the amounts of chemical substances discharged in the Norwegian sector via produced water from 23 oil producing platforms shows that the level of aromatics (mostly phenols and benzoic acids) is higher than the aliphatics (dispersed oil). Phenol and its lower alkylated homologues (C1 – C3) constitute the bulk of the phenols, while the C4 – C8 phenols, suspected of having endocrine impacts, constitute only about 5% of their total amount. Naphthalenes dominate the PAHs, while the heavier PAHs, potential carcinogenic and mutagenic compounds, are present in very low concentrations (OSPAR, 1998i).

Barium and iron are the most dominant metals, but smaller amounts of other metals are also found, especially nickel, lead and zinc. *Table 4.20* gives a partial view of the amounts of various priority contaminants in produced water discharged in the North Sea. As the amount of produced water has increased substantially (see section 4.7), it might be expected that the amount of chemicals associated with this particular source would follow the same trend. The sector concerned has considered that data on the exact composition of some chemicals are confidential to the relevant national authorities. Contracting Parties have data on the composition and quantities discharged and OSPAR is in the process of harmonising the format under which such data is collected and reported on a regional basis. Under these circumstances, it is not yet possible to present a complete overview of the total amount of offshore chemicals on a region-wide basis.

4.6.3 Industrial and municipal wastes

The dumping of chemical wastes into the North Sea ceased in 1993 (see section 3.9). However, direct discharge of wastes from the production of titanium dioxide still continued in 1994, mostly in French and UK estuarine waters (Seine, Humber and Tees). *Table 4.21* shows the decreasing trend in the amount of waste and related substances discharged during the period 1984–94 by France, the United Kingdom, Germany, The Netherlands and Norway. Sewage sludge dumping was completely phased out by the end of 1998 (see section 3.9.2).

Table 4.18 Discharges of priority substances (kg) via chemicals used in offshore oil and gas production in 1996 – available data are for the Danish sector only.

Substance	Quantity discharged
Cadmium (and compounds)	22
Mercury (and compounds)	25
Zinc	634
Lead	1 604
Chromium	124
Nickel	47
Copper	108

Table 4.19 Discharges (tonnes) of production, utility, and drilling chemicals from oil and gas production facilities in 1996 – available data are for the Danish sector only.

Substance / use	Total quantity discharged
Antifoams	0
Biocides	29
Carrier solvents	8231
Corrosion inhibitors	18
Defoamers	4
Demulsifiers	24
Dispersants	7
Drilling lubricants	89
Emulsifiers	7
Flocculants (water injection)	8
Fluid loss control agents	174
Gas treatment chemicals	0
Gels	1
Inorganic chemicals	2569
Lost circulation materials	35
Oxygen scavengers	1
Pipe release agents	5
Polymeric viscosifiers and filtrate reducers	227
Scale inhibitors	6
Scale inhibitors/encapsulators	123
Surfactants/detergents	0
Thinners	0
Viscosifiers	205
Weighting agents and inorganic gelling products	21 909
Others	2548

Table 4.20 Discharges of priority substances via produced water from offshore installations in 1996. Source of data: OSPAR (1998i,j).

Substance	Quantity discharged (t)	Average concentration* (mg/l)
Cadmium	0.6	0.01
Mercury	0.3	0.0003
Lead	6.9	0.09
Nickel	18.6	0.3
Total aromatics*	2130	28
Phenol/benzoic acids*	1345	14
Benzene	454	n.i.
PAHs (95% naphtalene)	28	0.36

Data show estimated discharges for Denmark, the Netherlands and Norway.

Information from the United Kingdom is not available.

* Data for Norway only.

n.i. no information.

4.6.4 Dumping of dredged materials

On account of the huge quantities of dredged material involved, the amount of associated heavy metals deposited in the marine environment is considerable. However, much of the trace metal content is of geological origin and many operations simply relocate the material rather than constituting a new addition to the environment.

Information provided by The Netherlands for dredging activities in the Dutch sector (OSPAR, 1997f) indicates that the anthropogenic contribution is very low for chromium, copper and nickel (0 – 2%), medium for mercury, arsenic, lead and zinc (30 – 50%) and predominant for cadmium (70%).

Despite the higher dredging activity in 1994 compared to 1990, the contaminant loads have shown a decreasing trend for materials originating from estuaries and navigation channels *(Tables 4.22–4)*. Most probably, this evolution reflects the reduction of heavy metal inputs to rivers and estuaries and the resulting improvement in the quality of dredged material. For the dredging of harbours no changes were observed.

Table 4.21 Discharges of waste and associated contaminants from the production of titanium dioxide. Source of data: OSPAR (1998e).

	1984	1990	1994
	(10^6 t)	(10^6 t)	(10^6 t)
Total waste discharged	1.076	1.094	0.468
Iron(II) sulfate	0.345	0.256	0.107
Sulfuric acid	0.598	0.510	0.260
	(t)	(t)	(t)
Chromium	511	491	217
Lead	23	18	4.6
Nickel	31	31	8
Copper	21	29	8
	(kg)	(kg)	(kg)
Cadmium	297	130	54
Mercury	128	72	31

4.7 Oil

4.7.1 Sources and inputs

The input of petroleum hydrocarbons in the North Sea is the result of sea-based activities (mainly shipping and offshore activities), coastal discharges of sewage and industrial effluents, dumping of oil-contaminated dredged materials, riverine inputs, atmospheric deposition and natural seeps. Discharges from sea-based activities and refinery effluents have been closely monitored over the past years, but there has been less focus on the inputs due to other sources. Methodological problems (sampling and analysis) are still to be solved for the evaluation of riverine oil input. Oil slicks are frequently observed originating from both ships and offshore installations, and are the result of both legal and illegal discharges or accidents. The majority of these slicks consist of ships' bilge oil, but crude oil and lubricating oils also occur along with non-mineral oils.

Offshore oil and gas industry

Figure 4.15 shows the quantities of oil discharged from 1984-97 (OSPAR, 1997g; 1999). A total of 11 800 t was discharged in 1995, of which 65% originated from produced water, 33% from cuttings, 2% from accidental spills and less than 0.01% from flaring operations. Between 1984 and 1995, the total amount of oil discharged has been reduced by about 50%, despite the fact that the number of offshore installations (oil and gas) increased from 143 to 458 units over the same period.

The amount of oil discharged via cuttings has been drastically reduced by 83% between 1984 and 1995. This is mainly due to the fact that diesel oil-based drilling muds were phased out in 1986 and oil-based muds (OBM) were partially replaced by water-based muds or muds containing organic-phase drilling fluids (OBF) after 1987. No OBM has been used in the Danish sector since 1991. In the UK

Table 4.22 Dredged material and associated contaminant loads (tonnes) dumped in the Greater North Sea in 1994 compared to 1990. Source: 1990 data from North Sea Task Force (1993), 1994 data from OSPAR (1997f).

	Amount dumped	Contaminant load									
		Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCBs	PAHs	Oil
Harbour areas*	99 763 914	29.0	11.7	293	1918	997	785	1946	6398	0.3	15	1988
Estuaries and Navigation channels*	87 813 089	31.3	5.4	216	699	300	378	750	1991	0.1	n.i.	n.i.
TOTAL (1994)*†	187 577 003	60	17	510	2600	1300	1200	2700	8400	0.4	15	2000
TOTAL (1990)†*	*136 037 942*	*71*	*19*	*720*	*2800*	*1300*	*1200*	*2700*	*7900*	*0.6*	*n.i.*	*n.i.*

* Including dumping in internal waters; † Total contaminant loads rounded to two significant digits; n.i. no information.

Table 4.23 Dredged material and associated contaminant loads (tonnes) from harbour areas, dumped in the Greater North Sea in 1994 compared to 1990. Source: 1990 data from North Sea Task Force (1993), 1994 data from OSPAR (1997f).

	Amount dumped	Contaminant load										
		Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCBs	PAHs	Oil
Belgium	5 839 198	10.0	1.5	51	175	115	83	268	601	0.06	n.i.	n.i.
Internal waters	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Denmark	3 275 590	0.09	0.04	0.08	10	3.2	2.0	7.6	26	n.i.	n.i.	n.i.
Internal waters	774 030	0.04	0.02	n.i.	5	1.5	0.02	3.8	12	n.i.	n.i.	n.i.
France	7 279 935	2.4	0.84	36	172	74	40	152	1 480	0.13	0.33	n.i.
Internal waters	1 143 805	0.23	0.04	5.2	17	5.5	6.2	24	39	0.01	n.i.	n.i.
Germany	26 169 000	0.73	1.4	17	70	25	27	67	163	0.04	n.i.	n.i.
Internal waters	26 136 000	0.73	1.4	16	69	25	26	66	161	0.04	n.i.	n.i.
Netherlands	33 610 638	10	4.3	171	509	260	199	556	1 716	0.05	15	1 988
Internal waters	9 055 828	2.7	1.1	50	145	72	54	149	488	0.03	4.4	463
Norway	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	207 327	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Sweden	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	27 350	0.003	0.002	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.a.	n.a.	n.a.
United Kingdom	23 354 876	5.6	3.6	19	982	520	435	896	2 411	n.i.	n.i.	n.i.
Internal waters	13 660 117	2.2	2.3	3.4	704	300	254	573	1 705	n.i.	n.i.	n.i.
TOTAL (1994)*	48 524 780	22.9	6.8	219	978	593	446	1 131	3 992	0.2	11	1 525
TOTAL (1994)**	99 529 237	29.0	11.7	294	1 918	997	786	1 947	6 397	0.3	15	1 988
*TOTAL (1990)***	*64 546 834*	*29.1*	*10.0*	*440*	*1 770*	*927*	*621*	*1 770*	*5 000*	*0.4*	*n..i.*	*n.i.*

* Excluding dumping in internal waters; ** Including dumping in internal waters; n.i. no or insufficient information; n.a. not applicable.

sector, no OBM cuttings have been discharged since 1996. OBM cuttings from Dutch and Norwegian installations are brought onshore for treatment and disposal. Additionally, OBM has been reinjected in the Norwegian sector (about three-quarters of the generated amount for 1997).

Due to the maturation of the producing fields and the extension of offshore activity, the amount of produced water has increased substantially during the past decade. As a consequence, the quantities of oil discharged via produced water increased from 1 717 t in 1984 to 7 648 t in 1995, of which 2 429 t (32%) originated from the 46 installations not meeting the 40 mg/l oil in water target standard (PARCOM Recommendation, 86/1). Installations in the UK and Norwegian sectors account for 77% and 18%, respectively, of the oil input from this source.

Accidental spills result in relatively minor amounts of oil entering the North Sea. Even if the total number of reported spills seems to follow an increasing trend (198 cases in 1986, 414 in 1992, 621 in 1995), the total

Figure 4.15 **Contribution of different sources of inputs of oil (in tonnes) from offshore installations. Source: OSPAR (1999).**

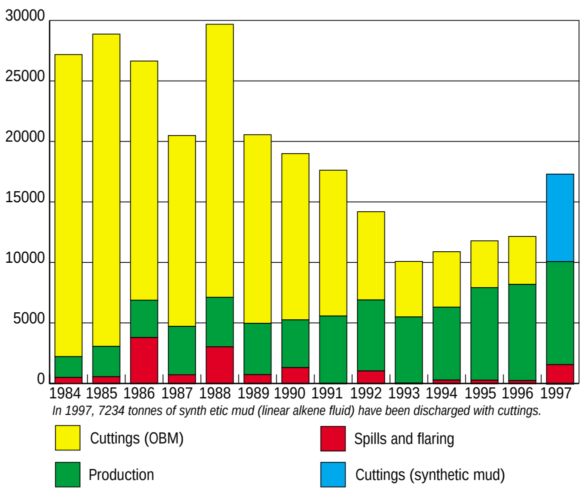


Table 4.24 Dredged material and associated contaminant loads (tonnes) from estuaries and navigation channels, dumped in the Greater North Sea in 1994 compared to 1990. Source: 1990 data from North Sea Task Force (1993), 1994 data from OSPAR (1997f).

	Amount dumped	Contaminant load										
		Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCBs	PAHs	Oil
Belgium	41 764 745	30	4.5	210	550	174	297	545	1 566	0.1	n.i.	n.i.
Internal waters	17 294 584	1.3	0.1	47	99	16	19	55	273	0.003	n.i.	n.i.
Denmark	404 825	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Internal waters	124 900	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
France	8 298 550	0.001	0.001	n.i.	n.i.	0.2	0.3	0.3	0.9	n.i.	n.i.	n.i.
Internal waters	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Germany	32 962 000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	32 962 000	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Netherlands	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sweden	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
United Kingdom	4 382 969	1.6	0.8	5.7	149	126	81	204	424	n.i.	n.i.	1.2
Internal waters	241 448	0.04	0.06	0.01	4.7	3.0	1.6	5.1	20	n.i.	n.i.	n.i.
TOTAL (1994) *	37 190 157	30.0	5.2	169	595	281	357	690	1 698	0.1	n.i.	n.i.
TOTAL (1994)**	87 813 089	31.3	5.4	216	699	300	378	750	1 991	0.1	n.i.	1.2
*TOTAL (1990)***	*71 491 108*	*41.4*	*8.7*	*279*	*1 040*	*398*	*584*	*971*	*2 900*	*0.2*	*n.i.*	*n.i.*

* Excluding dumping in internal waters; ** Including dumping in internal waters; n.i. no or insufficient information; n.a. not applicable.

quantity of oil discharged in this way has decreased markedly since 1986 (from 3 800 t in 1986 down to 270 t in 1995). In 1995 about 85% of the spills involved less than 1 t of oil.

Produced water overtook cuttings as the main source of oil input from offshore installations in 1993. Since then, the total oil input has been increasing again after the major reduction observed during the period 1984–93.

Shipping

The analysis of oil samples taken from the Danish, German and Dutch coastline between 1990 and 1992 indicates that bunker and lubrication oil residues are the main source of oil pollution in that zone. In the Skagerrak area, crude oil from illegal tank cleaning is also involved. For 1995, the amount of oil discharged into the North Sea area from shipping is estimated at 6 750 t.

Within the scope of the 'Bonn Agreement' (1983), regular pollution control flights have been conducted since 1986. Despite a steady increase in the number of airborne missions, the total number of observed slicks has decreased over the period 1989–96, although there was an increase of slicks reported in 1996 and, to a lesser degree, in 1997 for the area under Dutch surveillance. The average volume of identified oil slicks is reducing: out of a total number of 650 slicks observed in 1995 (against 1 104 in 1989), 519 were estimated to be less than 1 m^3, 107 between 1 and 100 m^3 and 2 greater than 100 m^3. An overview of the detected oil slicks (1998) is presented in *Figure 4.16*.

However, airborne missions can only detect a limited number of illegal discharges. For the marine area under Belgian surveillance, an estimate was based on the aerial coverage time, on the mean lifetime of oil slicks and on the influence of weather and sea conditions upon dispersion. It suggests that the reported oil quantities represent only 10% of the actual discharges (Schallier *et al*., 1996).

Refineries

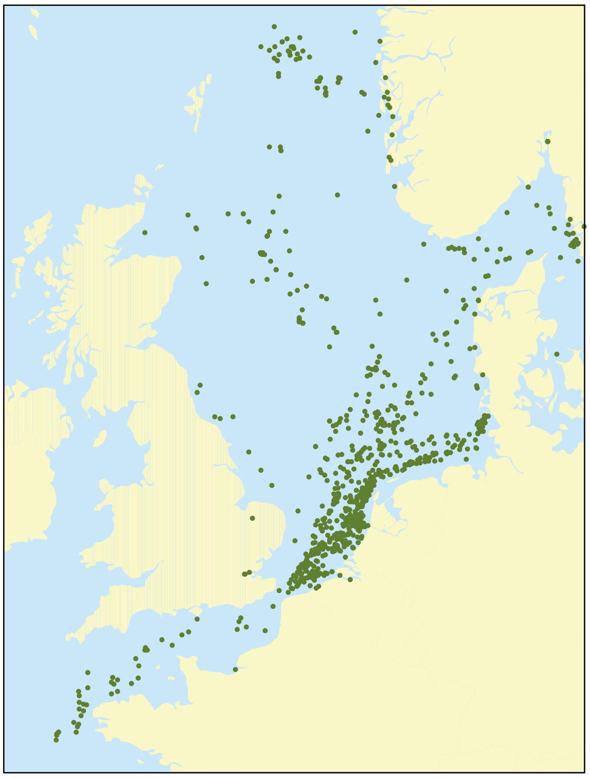
In 1997, 58 refineries were operated by nine OSPAR Contracting Parties, (OSPAR, 1999), discharging their effluents into coastal water (4), estuaries (29) and inland waters (25). About 83% of the total amount of oil was discharged into estuaries, mainly in the UK (58%) and in the Netherlands (15%). The total amount of oil discharged was 670 t in 1997, compared with 1 441 t in 1993 and 9 047 t in 1981. As a result of major treatment system improvements, there has been a strong reduction in the amount of oil discharged per tonne of oil processed (93% reduction between 1981 and 1997).

Other sources

Estimates of oil inputs from other sources have not been subject to regular reporting within OSPAR. However, for the Dutch sector of the North Sea it has been estimated that in 1995 atmospheric deposition and the dumping of harbour dredgings contributed 430 t and 2 000 t, respectively (Evers *et al*., 1997).

The total riverine input of oil was reported as 16 000 – 46 000 t/yr in the 1993 QSR. In the Dutch sector, it has declined from about 5 000 – 6 000 t/yr in 1980 to 580 – 1 235 t/yr in the period 1990–4. In 1995, inputs from the Rhine, Meuse and Scheldt together have been estimated at 1 000 t, which is only 15% of the total inland discharges and trans-boundary influx in the Netherlands for that year (6 640 t). Oil inputs from the Elbe amounted to 750 t/yr between 1989 and 1992. The 1993 QSR indicates that natural seepage of oil is of the order of 1 000 t/yr.

Figure 4.16 **Observed oil slicks in 1998. Source: Bonn Agreement (1999).**



4.7.2 Levels and visible impacts

Water

Values of 1 – 5 µg/l have been reported in water in the vicinity of oil platforms and in areas with intensive shipping. In the German Bight, the distribution of total hydrocarbon is mainly influenced by the Elbe plume, with concentrations ranging from 15 µg/l at the mouth of the estuary to 2 µg/l along the Frisian coast.

Oil slicks

Slicks continue to be predominantly observed along the shipping corridor between the Straits of Dover and the German Bight *(Figure 4.16)*. The rate of oiled seabirds (considered to be an indicator of oil pollution) showed a decreasing trend in nearly all the coastal regions of the North Sea over the period 1984–94 (see Chapter 5).

Sediment

Between 1 and 1.5 x 10^6 t of drill cuttings are currently estimated to lie on the seafloor of the North Sea (USEIA, 1998). Considerable amounts of oil adhering to drill cuttings have contaminated the seabed locally. In a study of 12 well sites on the Dutch continental shelf where OBM cuttings have been discharged during the 1980s and early 1990s, the chemical analysis revealed elevated oil concentrations at 5 of the locations, and traces of oil were visually observed at another 2 locations (Daan and Mulder, 1996). Maximum concentrations, measured over the upper 10 cm layer, were generally in the order of 10 – 50 mg/kg, but at one location a concentration of 200 mg/kg was found. Elevated oil concentrations only occurred within the first 100 – 250 m from the platforms, and it is suggested that the zone where persistent biological effects may be expected on the benthic community generally extends to a radius of about 200 m from OBM discharge sites. In the Norwegian sector, a survey of 14 fields showed that hydrocarbon contaminated sediments could in some cases extend to 2 – 8 km from the fields (Bakke *et al*., 1996).

4.7.3 Reference to EAC and BRC

No EACs or BRCs have currently been agreed by OSPAR.

4.8 **Radionuclides**

4.8.1 Sources and inputs

Data on all relevant sources of radionuclides are reported annually to OSPAR.

Artificial radionuclides

The main sources of artificial radionuclide inputs to the North Sea are discharges from nuclear fuel reprocessing plants (Cap de La Hague and, indirectly, Sellafield), the Baltic Sea outflow and inflow of Atlantic Water. The Baltic Sea outflow continuously supplies more ^{137}Cs (from the Chernobyl accident) than the reprocessing plants (Bailly du Bois *et al*., 1993). In the period covered by this report, the quantities of radionuclides released in liquid effluents from each installation were far below the discharge limits (OSPAR, 1998k).

The discharges of most radionuclides from Sellafield, located in the Irish Sea, and La Hague have reduced significantly in recent years but there have been important exceptions. Discharges of ^{129}I from Cap de La Hague have increased from 0.65 TBq in 1993 to 1.69 TBq in 1996 following the commissioning of a new reprocessing operation (Raisbeck *et al*., 1997). At Sellafield, releases of the actinides and ruthenium have decreased, but there have been consequential increases of the less radiologically significant ^{99}Tc from 6 TBq in 1993 to 150 TBq in 1996, and of ^{129}I from 0.16 TBq in 1993 to 0.41 TBq in 1996 (OSPAR, 1998k,1998l). In addition, remobilization of the actinides and ^{137}Cs from Irish Sea seabed sediments has resulted in the continuing export of these radionuclides via the North Channel to the North Sea (Kershaw *et al*., 1999). For example, it has been estimated that 350 – 570 TBq of ^{137}Cs was remobilised from the seabed in the period 1988–95 (Poole *et al*., 1997).

The total input of alpha-emitting radionuclides into the North Sea has decreased from 3 to 0.32 TBq/yr between 1993 and 1996, mainly caused by reduction of discharges from nuclear reprocessing plants.

The inputs of beta-emitting radionuclides excluding tritium and ^{99}Tc, have decreased from 250 TBq in 1993 to 182 TBq in 1996. Tritium (^{3}H) is the only radionuclide that is still discharged in significant amounts. The releases of tritium, in terms of activity, have increased from 11 000 to 16 800 TBq/yr between 1993 and 1996, mainly due to the discharges from the nuclear reprocessing plants (OSPAR, 1998k, 1998l). Tritium is of minor radiological significance as it is a low-energy beta emitter.

The annual discharges of other radionuclides were much lower than the maxima allowed for each of the nuclear installations (OSPAR, 1998k, 1998l).

Natural radionuclides

Inputs of natural radionuclides originate mainly from anthropogenic sources like mining and ore processing, burning coal, oil or natural gas in thermal power plants and the production of phosphate fertilisers.

The most important non-nuclear industrial process, giving rise to significant radioactive discharges is phosphate fertiliser production. About 1.6 x 10^6 t of phospho-gypsum waste were produced in 1993 in the OSPAR countries, of which about 40% was discharged into the marine environment (OSPAR, 1997h). This corresponds to annual discharges of 1.3 TBq ^{226}Ra, 1.12 TBq ^{210}Po and 0.1 TBq ^{238}U. The majority of the uranium contained in the phosphate ore is combined with the phosphoric acid produced, while radium and polonium are contained in the phospho-gypsum. Over the last few years, discharges of phospho-gypsum have tended to decrease. This development is expected to continue mainly due to the reduced production of phosphoric acid by European countries and to the land-based storage of the waste products. The discharge of phospho-gypsum into the sea has already been abandoned in several countries including France, the main producer of phosphate fertilisers in the EU.

4.8.2 Fluxes and transport routes of radioactive substances

The discharges from the Cap de La Hague reprocessing plant are transported by inflowing Atlantic water through the Channel along the continental coast, taking between 12 and 18 months to reach the coastal waters along the eastern North Sea (Salomon *et al*., 1995). The Sellafield discharges are transported from the Irish Sea around Scotland, after which a fraction of the radionuclides cross the North Sea. A transit time of 3 – 4 years is cited for this transport (Dahlgaard, 1995). However, recent observations and modelling of the discharged ^{99}Tc from Sellafield indicate more rapid transport through the North Sea. This is partly caused by the very strong natural flushing of the North Sea in the first half of the 1990s (see *Figure 2.15a*). Most of the radionuclide input is transported out to the north in the Norwegian Coastal Current.

4.8.3 Levels of radioactive substances: trends and spatial distribution

Water

The levels of ^{99}Tc observed in seawater samples collected in the North Sea were in the range 0.9 – 8.5 Bq/m^3 in 1996 and in the range 1.7 – 3.4 Bq/m^3 in 1997 (OSPAR, 1998m) A general increase over large areas of the North Sea was observed compared to the early 1990s, when the values were generally less than 1 Bq/m^3. The ^{210}Pb and ^{210}Po concentrations in water samples from Dutch coastal waters varied between 0.4 – 2.9 Bq/m^3 (the background concentration of ^{210}Pb and ^{210}Po ranges from 0.4 – 1.9 Bq/m^3). These levels can be influenced by discharges from the phosphate-ore processing industries, for instance the highest concentrations, up to 3.2 Bq/m^3 were found at locations in the Scheldt estuary close to past discharges of the phospho-gypsum industry. Measurements undertaken along the French Channel Coast showed a similar range of ^{210}Po concentrations of between 0.2 – 2.7 Bq/m^3 in filtered water. Activities in the North Sea, measured 30 km from the coast, were around 0.7 Bq/m^3 (^{210}Po and ^{210}Pb) and 5.3 Bq/m^3 for ^{226}Ra (OSPAR, 1997h). The natural concentrations of ^{226}Ra range from 0.8 – 8 Bq/m^3.

Sediments

Concentrations of artificial radionuclides in the North Sea sediments were generally low, except near the outlets. The specific activity of ^{134}Cs and ^{137}Cs, a major fraction of the Chernobyl fallout in 1986, decreased between 1990 and 1996. Along the North Sea coast of the UK, values after 1990 (0.3 – 0.6 Bq/kg for ^{134}Cs and 2 – 24 Bq/kg for ^{137}Cs) were much lower than the high specific activities determined in 1987 (values of 6.0 Bq/kg for ^{134}Cs and 65 Bq/kg for ^{137}Cs), confirming a decline in the effect of the Chernobyl accident (Camplin, 1992).

The background activity of natural radionuclides predominantly present in sediments is ^{40}K (2 – 1 000 Bq/kg), ^{232}Th (12 – 50 Bq/kg) and ^{238}U (2.5 – 186 Bq/kg) with its decay product ^{210}Po (100 – 280 Bq/kg) (Laane, 1992).

Measurements of ^{210}Po and ^{210}Pb concentrations in sediments along the French Channel coast in 1992 and 1993 showed values from 10 – 120 Bq/kg. For the same period, the measured activities of sediments along the Dutch coast were 20 Bq/kg (^{226}Ra, ^{210}Pb, ^{210}Po) and 1 Bq/kg (^{231}Pa) (OSPAR, 1997h). Recent measurements of ^{226}Ra in Rotterdam harbour revealed values of about 150 Bq/kg.

Biota

Typical levels of total alpha activity, mainly due to the natural radionuclide ^{210}Po are between 2 – 40 Bq/kg ww in fish and shellfish (Camplin, 1992). The measured ^{210}Po values in marine products show seasonal variations up to a factor of two, with the highest concentrations being observed in summer. Considerable variations are observed between species. The mean concentration in winkles near discharges is 260 Bq/kg, while it is 4 times lower in lobsters. Mussels affected by phospho-gypsum discharges have ^{210}Po concentrations in the order of 20 – 50 Bq/kg, 2 to 3 times higher than in unaffected regions. These values decrease with distance from the point of discharge, by a factor of 10 over 30 km (OSPAR, 1997h).

Concentrations of total beta-activities, mostly due to the natural radionuclide ^{40}K in fish and shellfish were 20 – 130 Bq/kg ww In mussels, total beta-activities were 20 – 60 Bq/kg ww The concentrations of beta/gamma-emitting nuclides in fish and mussels from the entire area of the North Sea were mostly undetectable, with the exception of ^{134}Cs and ^{137}Cs, for which values of 0.02 – 0.04 Bq/kg and 0.4 – 1.4 Bq/kg (ww) respectively, were determined (Camplin, 1992).

4.8.4 Radiation exposure from marine radioactivity and reference to recommended values

Radiation exposures from unenhanced sources of natural radioactivity are in most cases higher than those from artificial radioactivity. An estimate of the maximum likely individual dose to man from natural radionuclides amounts to about 2 mSv/yr. Most of the dose that humans obtain by consuming marine food is due to the alpha-emitter ^{210}Po which was found to be more strongly incorporated into several marine organisms than the other radionuclides (Köster *et al*., 1990). For example, consumption of 1 kg of shrimps from the Dutch coastal zone per year causes a radiation exposure of 25 µSv/yr. Discharges from the phospho-gypsum industry lead to radiation doses to seafood consumers from 100 – 380 µSv/yr.

As far as the artificial radionuclides are concerned, the ICRP (International Commission on Radiological Protection, 1991) recommended a principal dose limit received by an individual of 1 mSv/yr. Considering the public radiation exposure due to only artificial radionuclides, only ^{137}Cs is of any possible significance. However, environmental concentrations are very low. Artificial radionuclides contribute to the public exposure in the order of 1% (fish) and less than 1% (shellfish) of the ^{210}Po exposure.

For artificial radionuclides, the dose to man is at least two orders of magnitude less than the dose from natural radionuclides indicated above. Hence their concentrations in the environment are normally of no concern for human health. External exposure of the critical group based on concentrations of radionuclides in sediments is small, amounting to 10 µSv/yr or 1 % of the ICRP-recommended dose limit.

4.9 Nutrients and oxygen

4.9.1 Introduction

Nutrients (dissolved and particulate forms of nitrogen, phosphorus and silicon) play an important role in aquatic ecosystems, as they form the basis for primary productivity. Man-influenced aquatic systems are often characterised by high nutrient concentrations which may entail mass production of algae which in turn, when decomposing, can result in oxygen depletion. Marine areas such as the Kattegat, the eastern Skagerrak, and various Norwegian fjords, all suffer from periodic low oxygen levels (Preston, 1997). Decreased oxygen levels in late summer have been reported even in the central North Sea. Human impacts on nutrient concentration are mainly confined to the near coastal zone.

4.9.2 Sources and inputs of nutrients, input trends

There are various sources of nutrients, and most are linked to anthropogenic activities. Nitrogen in rivers originates mainly from the leaching of agricultural soils and from urban wastewater discharge. Nitrogen in the atmosphere (nitrous oxide and ammonia) originates from domestic and industrial combustion processes, traffic, as well as from agricultural sources such as animal housing and the spreading of manure. Phosphorus is mainly linked to urban wastewater and agriculture.

Figures 4.17 – 4.19 provide an outline of the annual direct, river, and atmospheric inputs of nutrients to the Greater North Sea between 1990 and 1996. Direct inputs decreased for nitrogen and phosphorus, while river inputs increased for nitrogen and phosphorus until 1995, before decreasing in 1996. For silicon, not being a constituent part of RID, there is insufficient information to draw a sensible conclusion. The pattern for riverine input follows the river water flow which may vary considerably from year to year. In particular, riverine inputs of nutrients were elevated by the large flows to the south-eastern part of the North Sea in the early months of both 1994 and 1995. The Fourth North Sea Conference Progress Report (4NSC, 1995) noted that since 1985 there have been substantial reductions in the input of phosphorus, of the order of 50% in ten years. Atmospheric deposition of nitrogen is variable, and no significant trend can be seen.

A major part of the nutrient inputs from land-based sources enter the North Sea via rivers. They account for 65 – 80 % of the total nitrogen inputs and for 80 – 85 % of the total phosphorus inputs. However, care should be taken in interpreting these values in terms of net inputs, since estuarine processes may seriously affect nutrient concentrations. In anoxic conditions, nitrogen compounds can be denitrified to gaseous forms and escape to the atmosphere and phosphorus can be temporarily stored in sediments.

Riverine inputs of phosphorus to the Wadden Sea have been reduced, causing decreased phosphate concentrations in most parts of this area (Bakker *et al.*, 1999). However input trends may vary on a local scale. Danish data for 1989–96 reveal that while direct inputs via waste water to marine areas were reduced by 66% for nitrogen and 81% for phosphorus, less reduction was seen in riverine inputs, especially nitrogen which showed no trend.

Marine inputs of nutrients i.e. those entering the Greater North Sea from adjacent seas, are difficult to assess. Model calculations (Norwecon model) reveal for the period 1976–95 mean nutrient fluxes of 4 000 ± 1 000 kt N/yr, 700 ± 200 kt P/yr and 3 800 ± 1 000 kt Si/yr (Laane *et al.*, 1996a). There is a high variability in the annual fluxes which results mainly from drastic changes in the transport of water into the Greater North Sea. Although these fluxes are substantially higher than anthropogenic inputs, it is important to note that only a proportion of these nutrients fluxes is available for primary production.

4.9.3 Fluxes

Internal nutrient fluxes within the North Sea ecosystem include various physical, chemical and biological processes. Processes affecting nitrogen fluxes are internal recycling of organic and inorganic compounds as dissolved inorganic nitrogen (DIN), uptake by phyto-plankton, particulate and dissolved organic nitrogen (PON and DON) mineralisation, sedimentation, DON exudation and nitrification. There are also source and sink

Figure 4.17 **(a) Direct discharges and (b) riverine inputs of total nitrogen to the Greater North Sea from 1990 to 1996 in kt/yr. Source: OSPAR (1998a).**

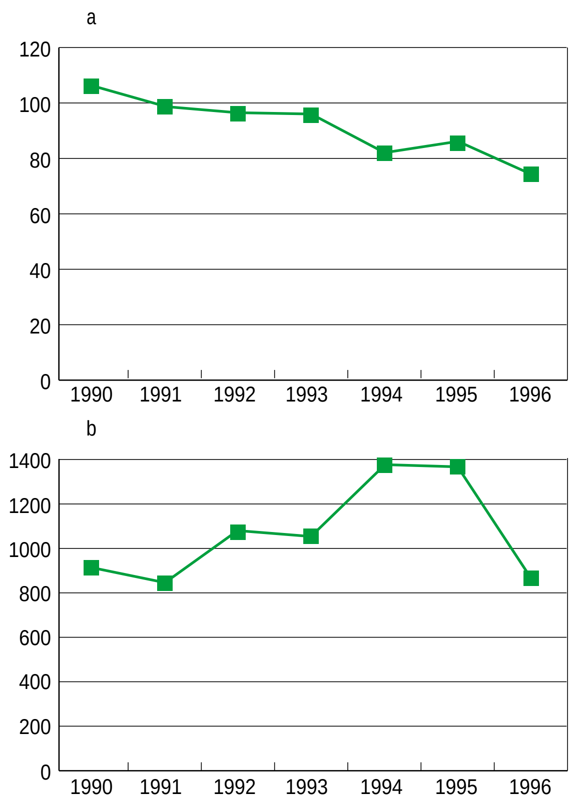


Figure 4.18 **(a) Direct discharges and (b) riverine inputs of total phosphorus to the Greater North Sea from 1990 to 1996 in kt/yr. Source: OSPAR (1998a).**

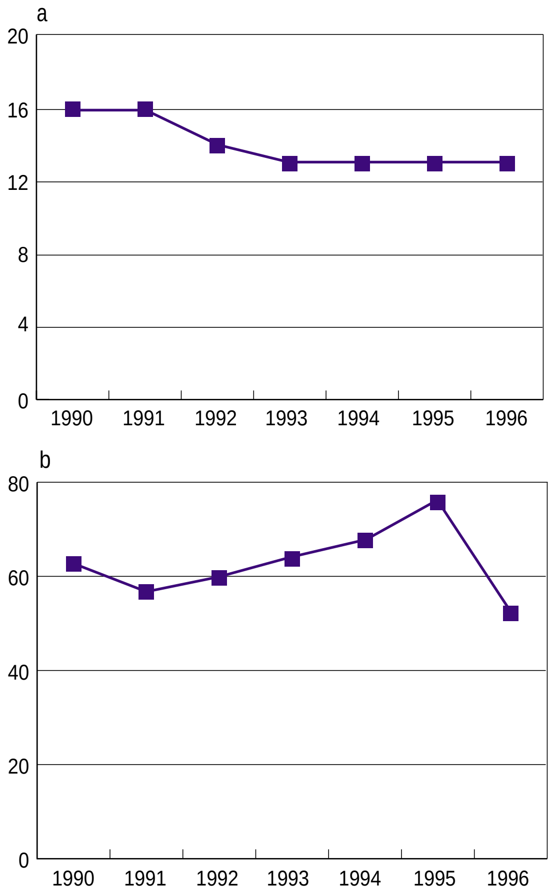
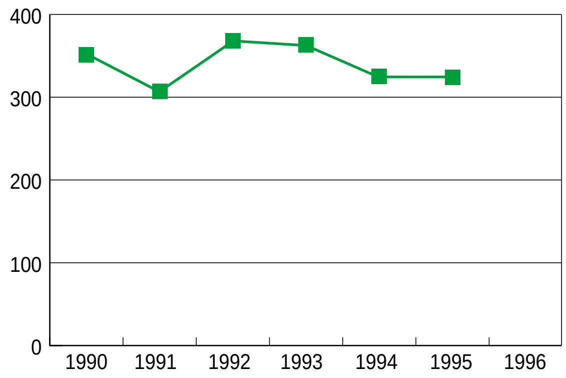


Figure 4.19 **Atmospheric inputs of total nitrogen to the Greater North Sea from 1990 to 1996 in kt/yr. Source of data: OSPAR (1998c).**



Note that no data were available for the year 1996

processes like biological nitrogen-fixation, sediment storage and denitrification. Phosphorus is subject to internal recycling processes such as phosphate uptake by phytoplankton, mineralisation of organic phosphorus, adsorption-desorption to particulate matter and to sink processes like burial. In the same way, silicon is taken up by phytoplankton and submitted to mineralisation and sedimentation processes.

Considering all the internal recycling processes of nitrogen, phosphorus and silicon, recent average data for the North Sea are rather scarce. In particular, there is little recent information about the importance of biological nitrogen-fixation in the North Sea area. It is generally believed to be a minor source of nitrogen in marine systems, although recent estimations made for the North Atlantic seem to show that this source is far from insignificant (Lipshultz and Owens, 1996). Early estimations by Capone and Carpenter (1982) suggest that nitrogen-fixation might account for as much as 2700 kt/yr in the North Sea area, although this value may be overestimated according to more recent observations.

Denitrification in the North Sea is assessed to be between 0.2 and 0.4 mmol N/m^2/day (Lohse *et al*., 1993). The North Sea sediments could account for a loss of 500 – 1000 kt N/yr.

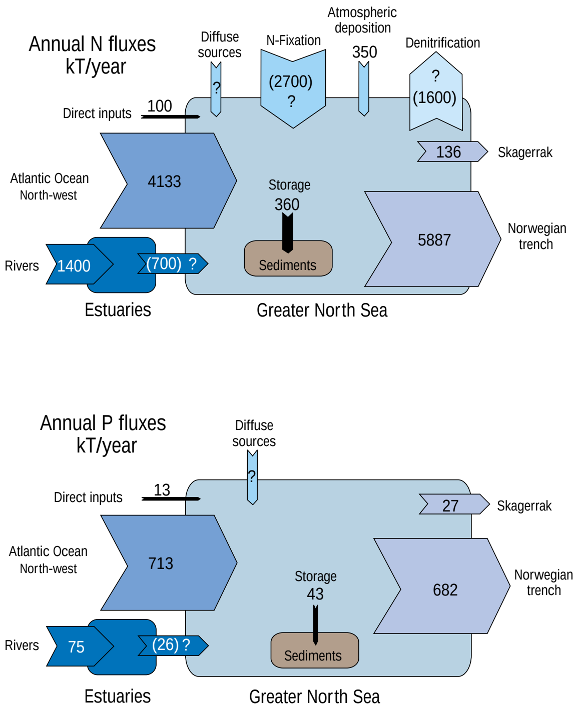
Figure 4.20 represents the summary of the nitrogen and phosphorus balance in the North Sea for the year 1995 including inputs and internal cycling fluxes, based on the approach used by Laane *et al*. (1993, 1996b). The values are in agreement with estimates provided by the European Regional Seas Ecosystem Model calculations, ERSEM (Radach and Lenhart, 1995). Still, as the collected data are from different origins, conclusions have to be drawn with great care. The most important conclusion is certainly the considerable impact of the exchange with the Atlantic Ocean on the nutrient cycling in the North Sea (see Chapter 2 and e.g. *Figure 2.15*).

4.9.4 Concentrations

Nutrient levels and spatial distribution in the Greater North Sea are presented for the years 1993–6 in *Figure 4.21*. Average winter concentrations for these years were not significantly different. Nutrient levels vary from high winter values to low summer values as a result of biological cycling.

Although no clear trend is occurring for the North Sea considered as a whole, this is not the case in local areas that are directly influenced by anthropogenic inputs. For example, a significant decreasing trend (especially for phosphorus) was detected in Danish waters (1989–97) and the German Bight. The decrease of the phosphorus concentrations in nearly all Danish areas is due to a significant decrease in the load from effluents. The same trend was also pointed out for phosphorous in the Wadden Sea (see section 4.9.2).

Figure 4.20 **Annual nitrogen and phosphorus fluxes within the Greater North Sea area. Source of data: sewage and riverine input data: OSPAR (1998b); atmospheric input data: OSPAR (1998c); estuarine inputs calculated according to Nixon *et al*. (1996); Atlantic ocean inputs and sediment storage: Radach and Lenhart (1995); N-fixation: Capone and Carpenter (1982); denitrification value: Seitzinger and Giblin (1996); output calculations to Norwegian Trench and Baltic Sea: budgeting to satisfy steady state conditions (inputs = outputs).**



In the Kattegat and Belt Sea, the winter concentrations of nitrate most often exceed the concentrations determined from pure mixing of Baltic water with Skagerrak water. These excess concentrations are positively correlated to the direct input from land (Denmark, Sweden and Germany), from the atmosphere and also to the freshwater runoff. This means that in this area the local nitrogen load influences the local concentrations significantly. The excess concentrations for phosphate are not strongly correlated to land-based load as sediment release is of great importance to phosphorus concentrations in the Kattegat and the Belt Sea.

4.9.5 Reference to background values

For the reasons given in section 4.3, BRCs were not established for the nutrients nitrogen and phosphorus. The present nutrient distribution shows a significant departure from values mentioned in Table 4.6 especially in areas that are directly under the influence of anthropogenic inputs.

4.9.6 Oxygen

The introduction of large quantities of nutrients can lead to increases in primary production and algal biomass. Degradation of this biomass requires large quantities of oxygen. This can be a major problem in areas with restricted water exchange capacity (such as some Swedish coastal waters) or stratified bodies of water. In these cases major algal blooms have led to serious damage to aquaculture through oxygen depletion and toxin formation (Preston, 1997).

Oxygen depletion can occur in summer periods after water column stratification with limited exchange of dissolved oxygen between the water layers. Generally, since the North Sea is only occasionally stratified, oxygen deficit problems are minor although from time to time they have occurred. However, for stratified waters like the Kattegat, oxygen depletion problems are important (Christensen *et al*., 1998). Statistical analyses of data from Danish fjords have shown that nitrogen loading has the most significant anthropogenic influence in relation to an occurrence of oxygen depletion. Model calculations from the Danish EPA showed that a 50% reduction of the actual nitrogen load would result in an almost equal reduction of the duration of anoxia in these environments (from 493 to 268 days). Since the beginning of the 1990s, no severe oxygen depletion has occurred in the German Bight, but in certain parts low oxygen concentrations still occur occasionally in late summer (e.g., 1994).

4.10 **Observed trends in relation to measures**

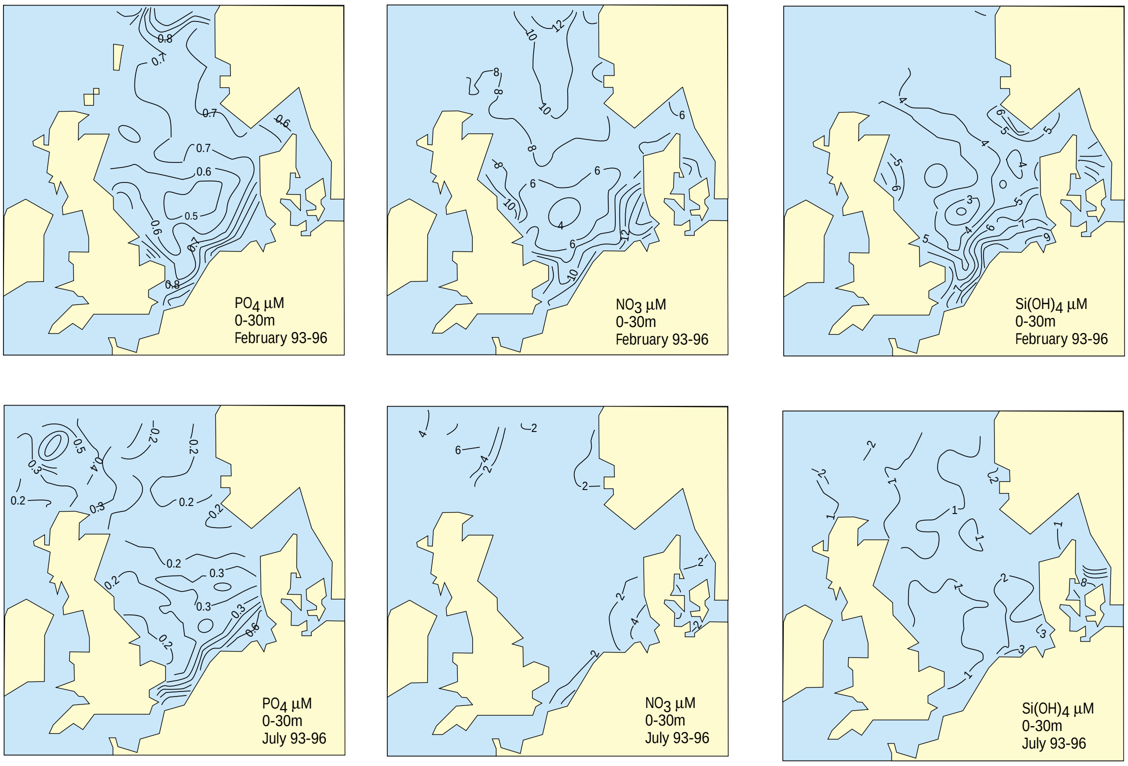
In this section, only clear trends determined with rigorous statistical tests are discussed. Compounds not mentioned here, either do not show any clear trend or insufficient data are available to draw any conclusions. When possible, a link with specific policy measures has been made.

4.10.1 Trace metals

During the last decade, very significant reductions in the discharges and emissions of heavy metals have been achieved by the nine countries involved in the catchment area. Most countries have reached (or are close to) the 50% reduction target set for the period 1985–95.

During this period, cadmium inputs to the receiving waters have been reduced by about 80%. This is mainly due to changes in industrial practice, the adoption and implementation of BAT (Best Available Technology) and

Figure 4.21 **Average distribution (for 1993–6) of phosphate (PO_4^{3-}), nitrate (NO_3^-) and silicate ($Si(OH)_4$) concentrations in surface waters of the Greater North Sea for a winter (February) and a summer (July) situation. Source: Radach and Genkeler (1997).**



to better control of the effluents in the fertiliser, non-ferrous metal, iron and steel and surface treatment industries. Regulations concerning the use of cadmium in batteries and the substitution of cadmium in end products are also involved. The release of cadmium to the atmosphere has been reduced by 55 – 90% during the same period, mainly because of measures taken for flue gas treatment at coal fired power plants and due to the decrease of cadmium emission from waste incineration units.

For mercury, the closing down of important mercury emitters in the former GDR, emission reductions following OSPAR measures (Decision 90/3: a reduction of mercury emissions to less than 2 g/t before 1997, and a recommendation to phase out mercury cells in chlor-alkali plants by 2010) taken at chlor-alkali plants, the installation of gas treatment at power and incineration plants, the substitution of mercury in user products and closer control of diffuse sources (dentistry) have resulted in decreases in discharges of between 60 and 100% to the aquatic environment and of between 25 and 80% in emissions to the atmosphere. The first objective of Decision 90/3 has, on average, been met.

Between 1985 and 1995, waterborne discharges of lead also diminished by between 45 and almost 100% as a result of measures taken in the non-ferrous metals industry, better control of diffuse sources and the recollection of lead batteries. The decrease of between 60 and almost 100% in lead emissions to the atmosphere is the clear consequence of the increasing use of unleaded petrol. (Leaded petrol was banned in Germany in 1988 and in Denmark in 1995. In other countries, reductions in the use of leaded petrol are following the pattern of automobile renewal). Flue gas treatment has also contributed to this trend. The reduction of copper emissions to the air of between 25 and 95%, and to receiving waters of between 25 and 85%, is the result of BAT implementation in the iron, non ferrous and surface treatment industries, and gas treatment at power and incineration plants.

Because of the short residence time of heavy metals in the atmosphere, the various measures taken to control airborne emissions have resulted in a clear decrease in heavy metal deposition to the North Sea (about 30% for cadmium and lead, and 20% for mercury between 1990 and 1995). This pattern has followed the trend already observed in the late 1980s, so that the atmospheric input of cadmium and mercury to the North Sea has been halved since 1987 and reduced by about 60% for lead. This is in contrast with waterborne inputs where only mercury has shown a general decreasing trend over the period 1990–6, while cadmium, lead and copper inputs have not been reduced over the same period (except for 1996). This is mainly attributed to the variation in the hydrological conditions over the period, in particular the large riverine flows to the south-eastern part of the North Sea in 1994 and 1995, but the existence of terrestrial reservoirs (such as contaminated land and sediments) or uncontrolled diffuse sources are also suspected.

As a consequence, only a limited number of decreasing trends have been reported for the concentration of heavy metals in various marine organisms. For seawater and sediments, water bodies such as estuaries, fjords or enclosed seas are more exposed to anthropogenic contamination, but the response to the measures taken is generally more clearly noticeable than in the open sea. This is also the case for areas subjected to dumping. In spite of higher dredging activities, the related contaminant loads have shown a decreasing trend, probably reflecting the reduction of contaminant inputs in rivers and estuaries.

4.10.2 Persistent organic compounds

For persistent organic compounds, data were only available for PCBs and PAHs, but no clear trends can be observed. The use of PCBs was banned in the eighties (more than 90% of the total release of PCBs occurred before 1980; 4NSC, 1995), but despite this measure, only a slow downward trend could be observed due to the fact that polluted sediments act as a source of these contaminants. In the German Bight, α-HCH and γ-HCH have shown a strong decreasing trend over the past 20 years.

In the few places where dioxin levels in biota have been monitored, concentrations have been decreasing since 1990 after reduction measures were taken at industrial sources. However, local concentrations have remained at such a high level that it has led to negative advice on consumption. These high concentrations are probably caused by contaminated sediments and food chain transport.

4.10.3 Oil

In the offshore oil and gas industry, the discharge of oil via cuttings has been strongly reduced (by more than 80%) over a period of ten years, mainly because oil-based drilling mud has been replaced by water-based mud. However, with the amount of oil discharged via production water increasing considerably over the past decade, total oil inputs are increasing slightly after a period of strong reduction.

Illegal discharges from ships continue to be a matter of concern. Oil slicks are still detected along the main shipping corridor in the North Sea, although their frequency and volume seem to have generally decreased.

Application of BAT in the petrochemical industry has been very efficient in reducing the amount of oil discharged. This sector has become a marginal contributor to oil pollution in the North Sea.

4.10.4 Radionuclides

The amounts of artificial radionuclides excluding the less radiologically significant isotopes ^{3}H and ^{99}Tc, discharged annually to the North Sea, have generally decreased over the period 1993–6 and they were much below the permitted limits. Inputs of natural radionuclides, apart from activities related to nuclear facilities, also show a decreasing tendency, mainly due to reduced production of phospho-gypsum by European countries. This development is expected to continue in the future. Radiation exposure from artificial radioactivity is generally much lower than exposure from unenhanced sources of natural radiation and as such it poses no concern for human health.

4.10.5 Nutrients

The general trends for nutrient inputs to the North Sea and nutrient concentration distribution have already been briefly discussed in section 4.9.

The situation concerning nutrients and associated eutrophication effects is rather complex. In those areas almost exclusively influenced by waters from the Atlantic no significant trends in concentrations could be seen over the last decade. A number of areas under the influence of inputs from land-based sources continue to suffer from eutrophication. Trends of decreasing oxygen concentrations, which may be due to eutrophication, enhanced sedimentation and organic matter decomposition, have been documented for deep water in the Kattegat and the basin water in Swedish and Norwegian fjords. However, some improvements with respect to nuisance algal blooms, oxygen depletion and benthos/fish kills are seen in many areas of the North Sea. Significant decreases in concentrations of phosphorus were observed in Danish waters, the German Bight and the Wadden Sea. From 1990–6 direct nitrogen and phosphorus inputs to the North Sea decreased by about 30% and 20% respectively, mainly due to improved waste water treatment. Riverine input increases were mainly due to higher precipitation and, as a result, higher leaching of nitrogen and phosphorus from agricultural soils during 1994–5. For atmospheric inputs, no distinctive changes could be detected.

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.

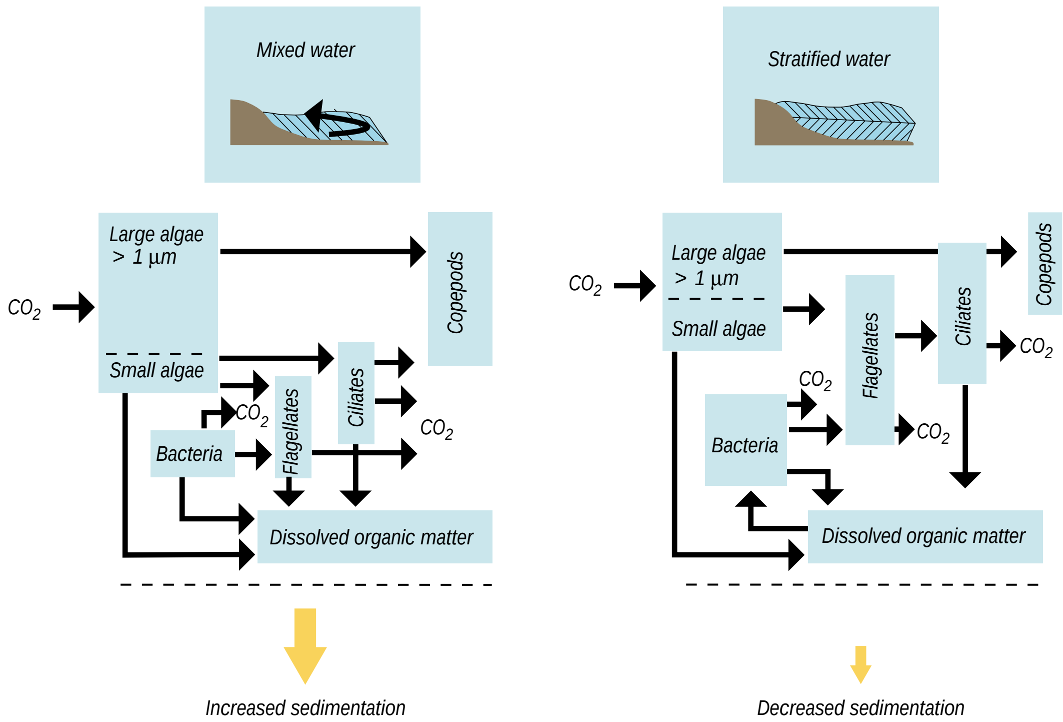
Long-term biomass estimates of micro- and nanoplankton in the German Bight near Helgoland indicate sources of variation including both seasonal succession and changes due to shifts in the hydrographic structure of the nearby stratified water masses. Any changes due to increasing nutrient concentrations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

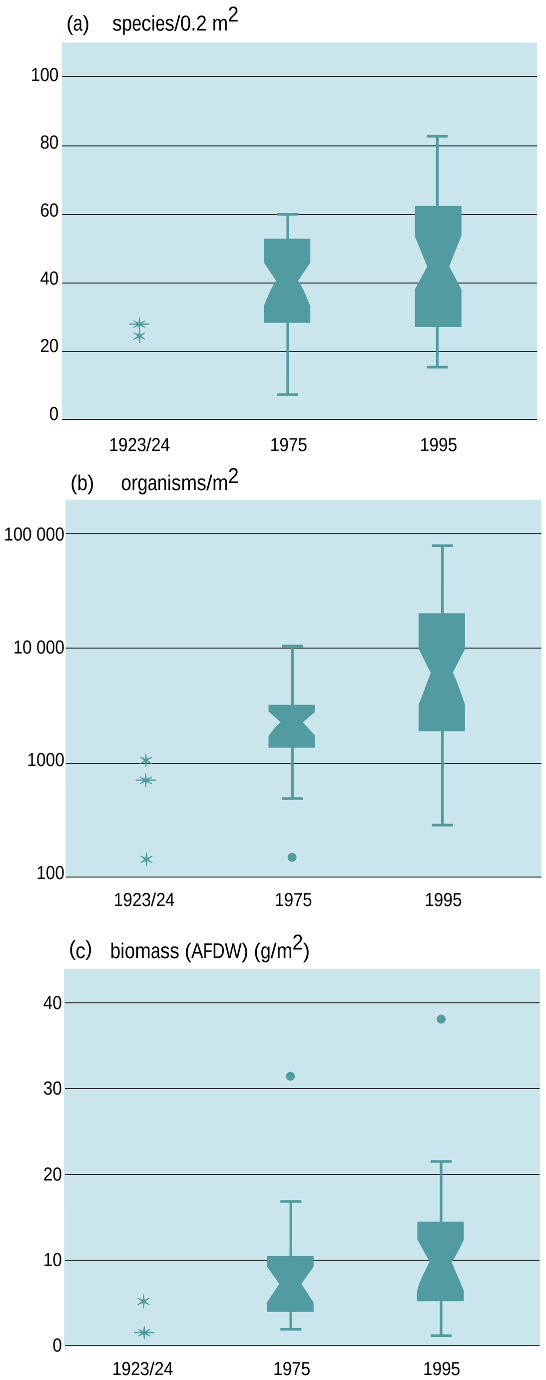
Microphytobenthos is a primary source of nutrition in shallow waters for larger grazers and fish (e.g. mullet, *Crenimugil labrosus*). Microphytobenthos suspended by wave action have been calculated to constitute up to 90% of the primary production in the water column and are probably important as a 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.

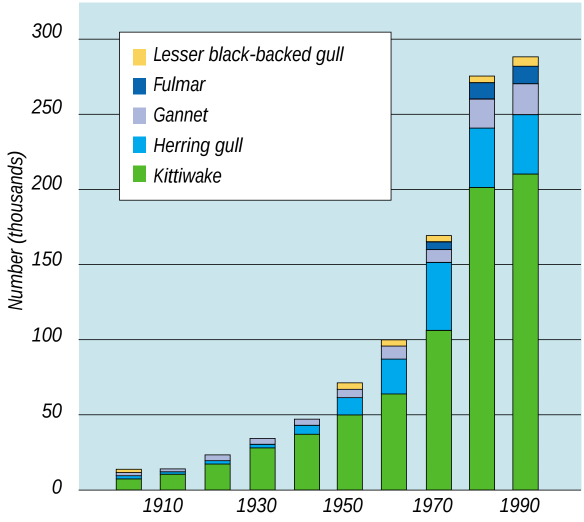
Fish species diversity is low in the shallow southern North Sea and eastern Channel and increases westwards. Species diversity is also generally higher inshore (Greenstreet and Hall, 1996) as the variety of sediment types and spatial niches increases.

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.

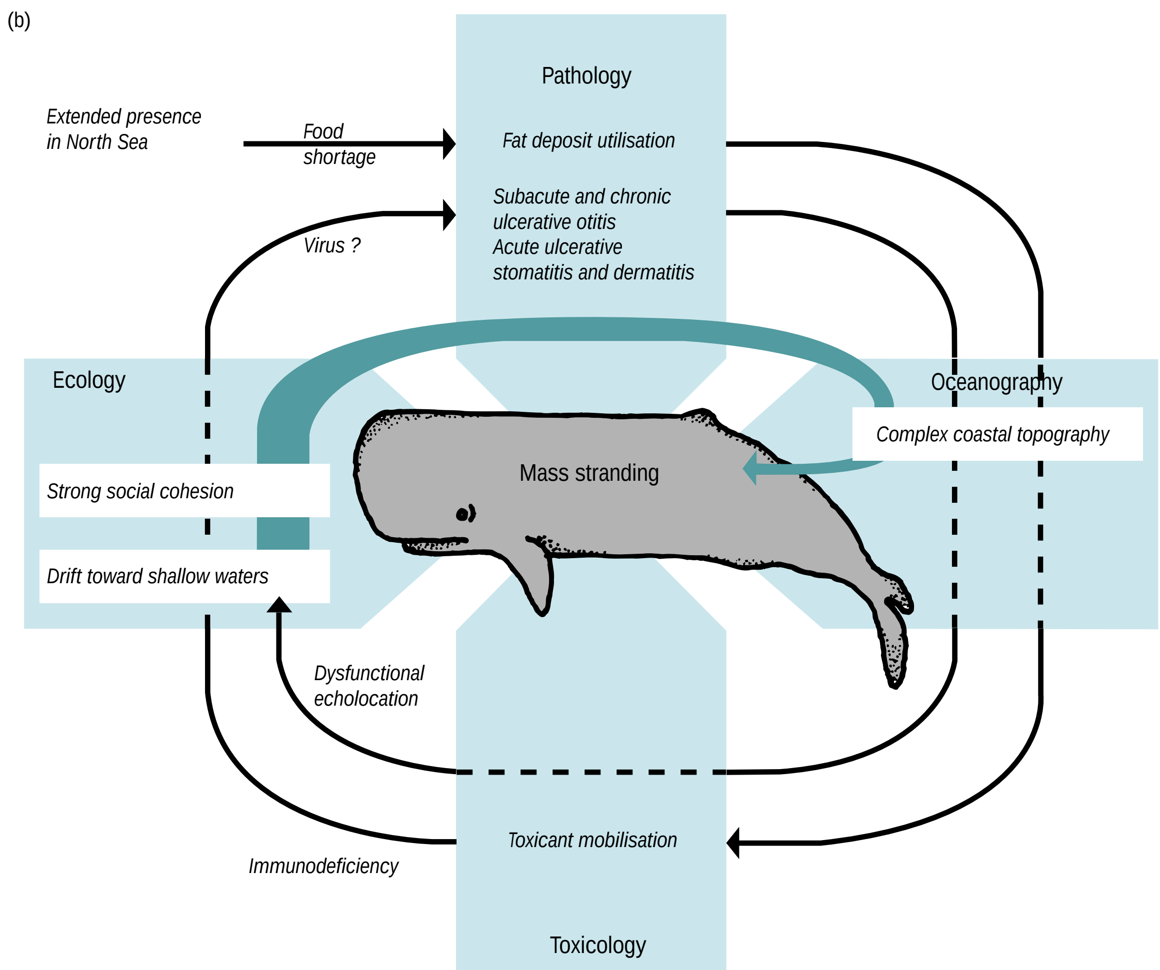
An offshore and an inshore group can be identified among the seabirds. The offshore group includes fulmars, petrels, gannets, some gulls, and most auks. These birds breed on the coasts of the North Sea and the Channel, but frequently feed far offshore with a significant portion of their diet likely to 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

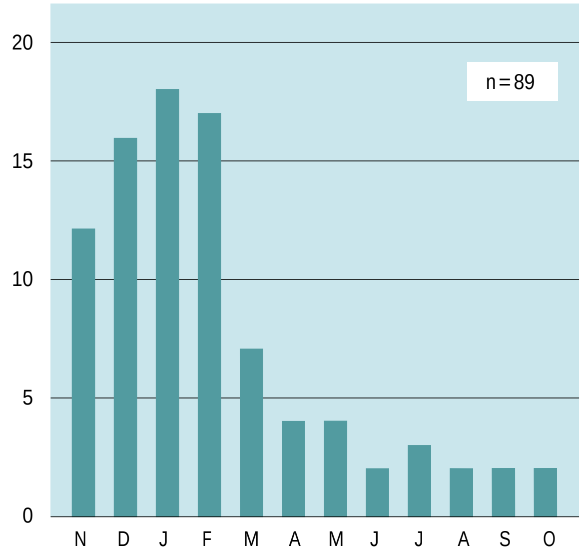
Counts of common seal numbers (1994–6) estimate the current North Sea population at 36 000 seals. The Wadden Sea population was reduced from 10 000 to 4 000 after the 1988 epidemic. Since 1989 numbers have increased to more than 14 000 (counted in 1998; Reijnders and Reineking, 1999). On balance, therefore, 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.

5.3.2 Harmful algal blooms

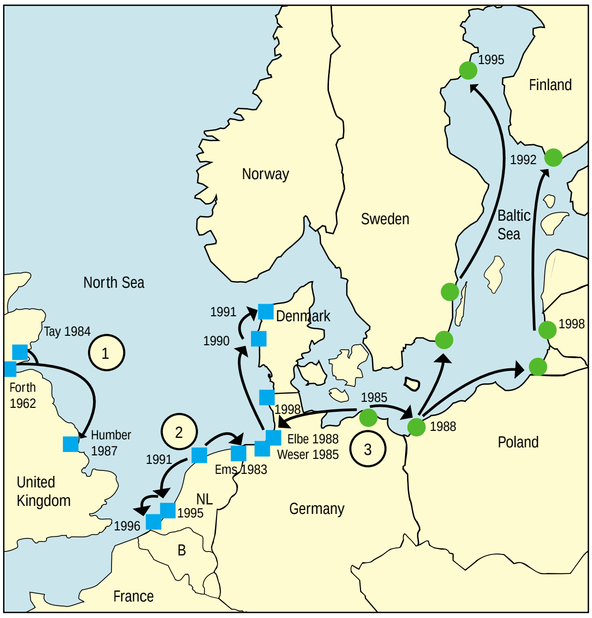
Approximately twenty North Sea phytoplankton species produce toxins, some of which affect fish directly (ichthyotoxins). Their effect on man is usually indirect. Mussels concentrate toxins in the hepatopancreas and human consumption of such mussels occasionally causes fatal poisoning. Poisoning is classified 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

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.**



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).**

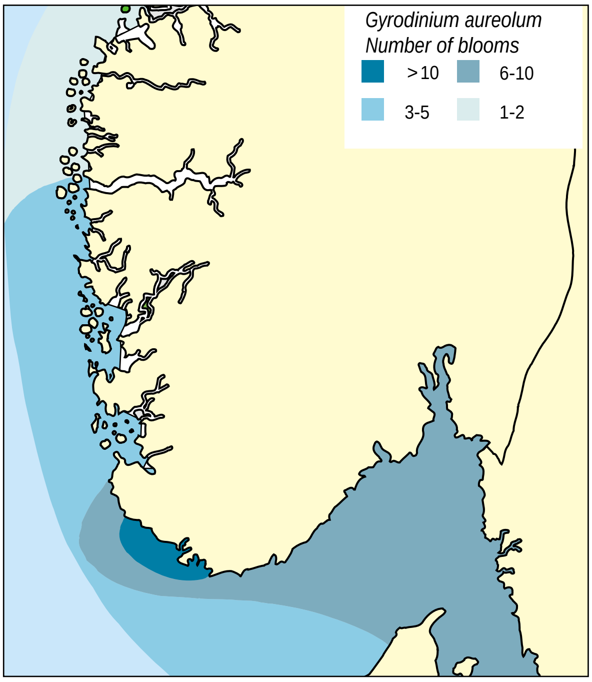
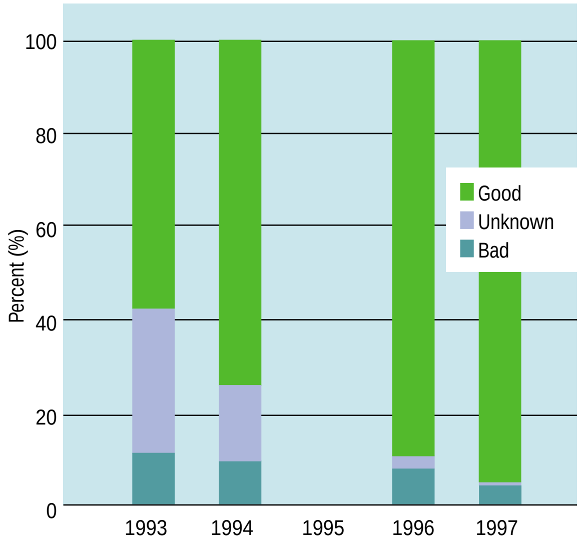


Figure 5.8 **An overview of bathing water quality for the years 1993 to 1997 based on an assessment of the data published by the European Commission (Forbes and Brans, unpubl.).**



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

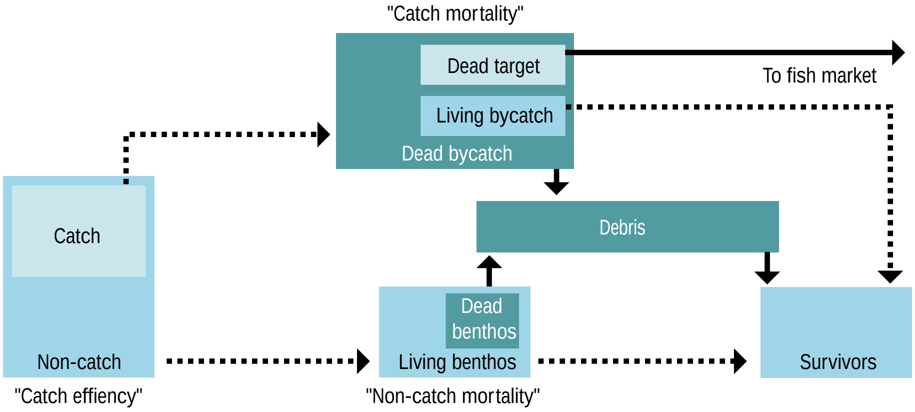
There are three principle effects of fishing activity on North Sea ecosystems. The first is due to direct fishing pressure. Capture of fish and shellfish leads to mortality of both target and non-target species. A second important effect is due to the practice of discarding which can significantly impact 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).**



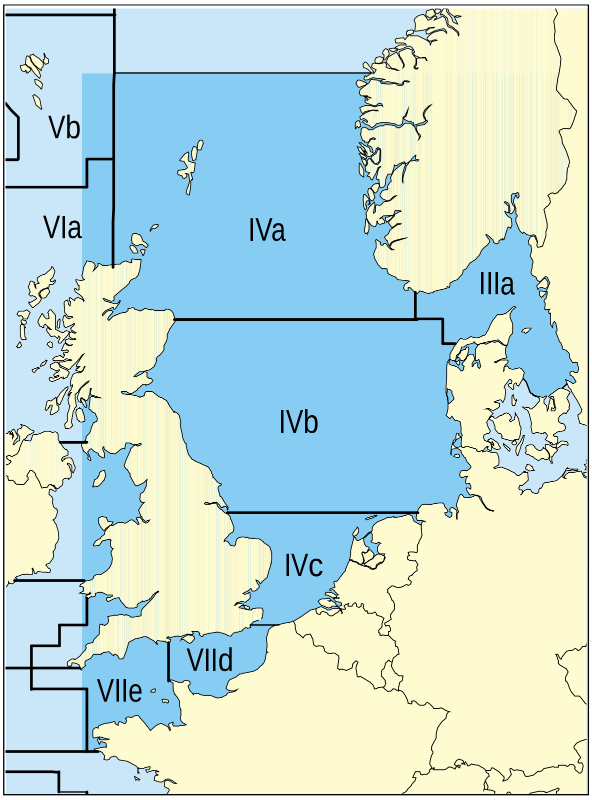
predation rates and the resultant shifts in trophic dynamics and community structure are likely important determinants of present day ecosystem functioning.

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.

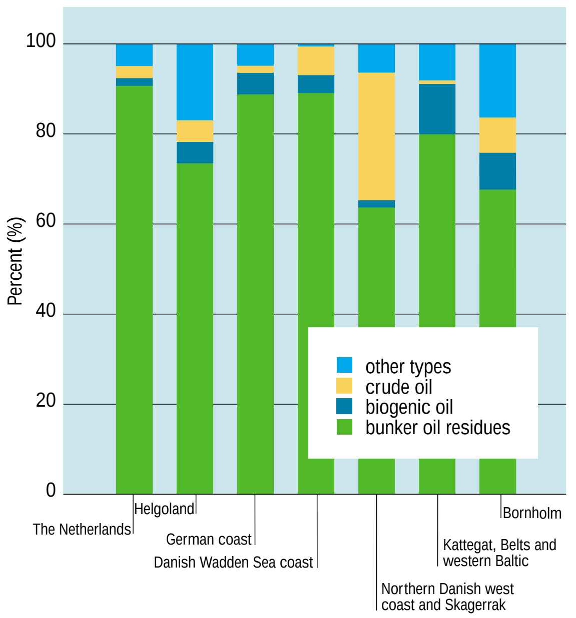
Many organisms carried within ballast water (see section 5.3.1) are killed either in transit or when ballast water is discharged. Some, however, survive and can be a threat to native species. Another important impact of shipping is related to the contamination caused by the use of TBT (see section 5.3.13)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

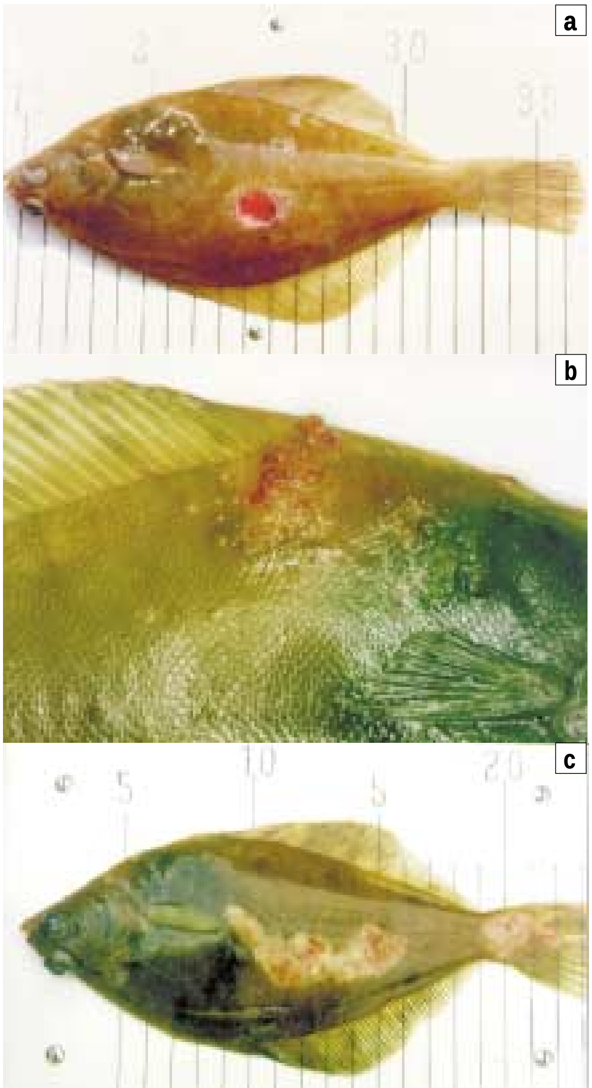
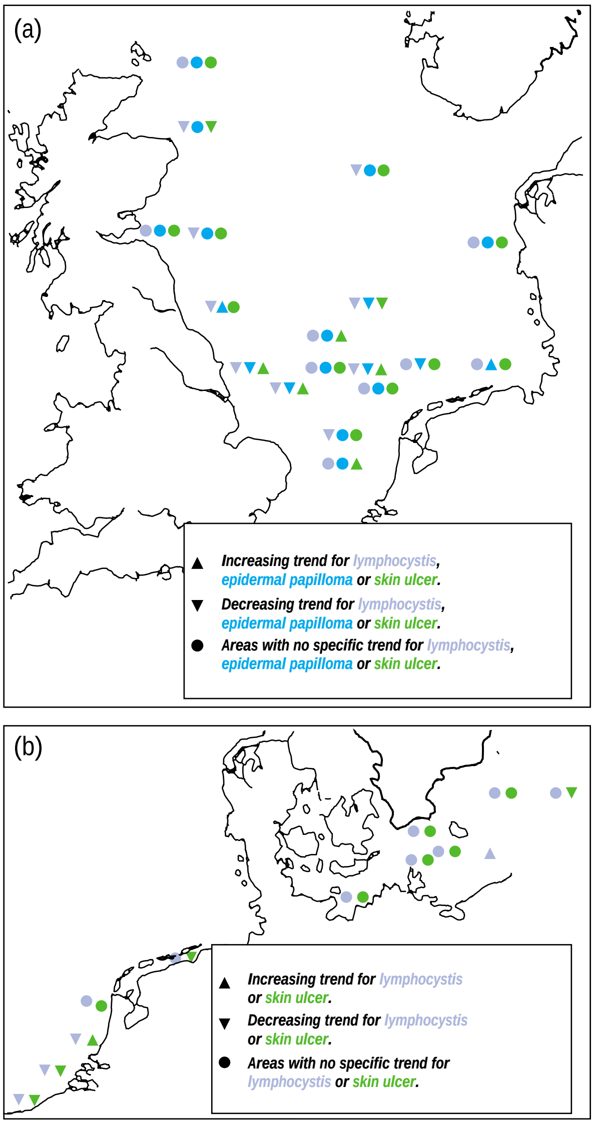


Figure 5.13 **Recent developments (since 1992) in the prevalence of lymphocystis, epidermal papilloma and acute/healing skin ulcer in (a) common dab and (b) in flounder.**



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.

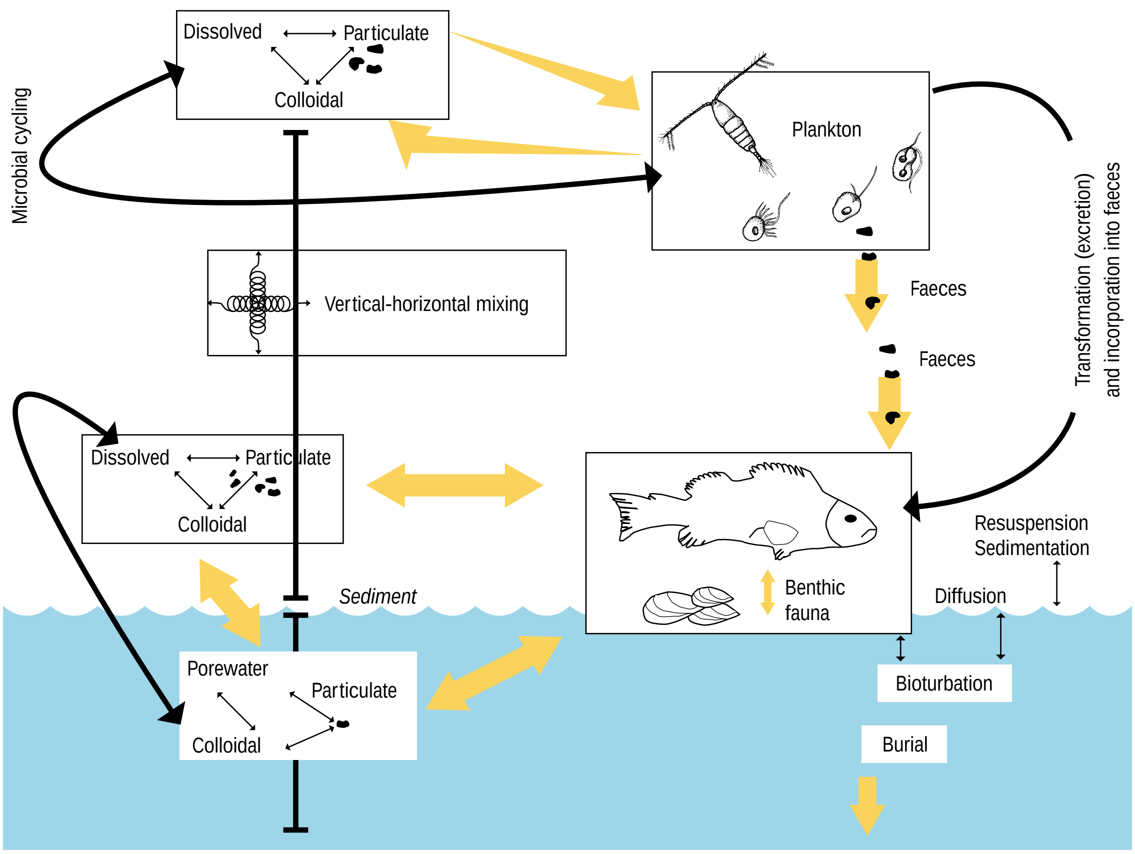
In general, risks to the ecology of the North Sea from metals appear to stem from copper contamination, (mainly due to effects on the production at lower trophic levels such as bacteria and phytoplankton), cadmium and mercury (on top predators) and lead (on predators of shellfish). These effects are 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.

chapter 6

Overall assessment

6.1 Introduction

This chapter provides an overall assessment of the quality of the Greater North Sea area (Region II), and the relevant human impacts, based on information from Chapters 2 – 5. It attempts to combine this information to identify impacts of concern and any significant gaps in knowledge. The present QSR addresses the Joint Monitoring and Assessment Programme (JAMP) issues, and answers to the best possible extent the questions that have been raised.

Section 6.2 gives an overview of human pressures resulting from both land-based and sea-based activities. The pressures have been ranked according to their relative impacts on the North Sea using a process of assessment involving structured expert judgement. For each of the different human pressures identified as being of greater concern, the impact and any changes are evaluated, the effectiveness of existing measures is discussed, and recommendations for policy options to be considered by the appropriate authorities are made.

The basis for the assessment is principally formed from the results of joint monitoring activities carried out by the coastal states as well as from national monitoring. However, present monitoring programmes do not systematically cover the entire area (section 4.1). This limits the assessment of its status. Modelling techniques are used to improve our understanding of the present status and developments, and the implications of human activities. Application of assessment tools such as models, 'Ecotoxicological Assessment Criteria' (EACs) and 'Background/Reference Concentrations' (BRCs) requires a certain amount of caution, as uncertainties still exist. Also, the expert judgement process should be seen as a tool and not as a definitive ranking system.

In section 6.3, the main limitations in our knowledge that are relevant for making a quality status assessment are identified. It focuses on the lack of data and of statistical information, on research needs (both in the fields of natural sciences and socio-economics) and on reference values and assessment tools. In addition, problems of comparison between OSPAR regions are addressed. Where appropriate, the precautionary principle should be applied.

The next section (6.4) presents a concise overall assessment of the health of the North Sea, with special attention given to the combined effects of impacts.

The concluding section (6.5) is dedicated to the main conclusions of the assessment, an outlook towards further activities and general recommendations.

6.2 Assessment of human impacts

The North Sea has a long history of multiple use by people from many nations. There is awareness of the need to safeguard the marine ecosystem and to achieve sustainability in respect of human use. Knowledge of the main human pressures and understanding their impact is essential to the development and implementation of effective measures to reach such sustainable use. In order to determine the relative importance of the various human pressures a structured prioritisation method has been applied. A hierarchical scheme of criteria, related to an overall objective of a healthy ecosystem and sustainable use of the North Sea, was used. Thirty-two human pressures were defined and each was evaluated against these criteria, taking into account severity, spatial scale and recovery time. A more extensive description of the assessment process, including its strengths and weaknesses, is given in RA (1998). On the basis of scores and argumentation, the human pressures were ranked into four priority classes ***(Table 6.1)***. The classes are described as: class A: highest impact; class B: upper intermediate impact; class C: lower intermediate impact; class D: lowest impact. It must be underlined that this exercise was performed mainly on a qualitative basis. There is scope to repeat it in the future, using more quantified criteria.

While the division into classes was established as firmly as the process permits, the order within each class was not considered to be significant. The reasons for placing pressures in the higher impact classes, A and B, are described in the following sections. For this description, human pressures within a given class are grouped together according to subject, e.g. fisheries. For information on pressures in classes C and D, the text of chapters 2 – 5 should be consulted. Although the impacts of these pressures are perceived to be less than those in classes A and B for the entire North Sea, they may, however, be of more serious concern in combination with other human pressures.

Initially, in addition to the thirty-two pressures, a thirty-third pressure was defined as ‘various human activities contributing to climate change’. However, in view of the very broad scope of its causes and effects, it was considered inappropriate to compare this item directly with the other pressures. Since climate change has, potentially, a very significant influence it is addressed first in the next section.

6.2.1 Climate change

The climate of the North Sea and adjacent areas is, in general, strongly influenced by climatic oscillations originating in the North Atlantic Ocean, whereas in the eastern North Sea ingressions of continental climatic conditions sometimes occur. The North Atlantic oscillations control the variability of water inflow from the North-east Atlantic into the North Sea and the large-scale atmospheric circulation. The North Atlantic Oscillation index is a measure of the intensity and persistence of westerly winds over the North Atlantic. Its impact, which extends to the North Sea, affects cloud cover (precipitation and light), upper ocean turbulence and heat flux and is, therefore, an important factor in the ocean’s productivity. Wind speeds showed no significant trend over the last 100-year period, but an increase has been observed since the 1960s.

Sea surface temperature series show a weak upward trend that is in agreement with the global temperature increase of about 0.6 ºC in 100 years. As Atlantic water is the main source of nutrients and supply of plankton for the North Sea, climatic variables have been demonstrated to influence the recruitment and growth of several fish species and the migration of adult fish into the northern North Sea.

It is difficult to determine the possible regional effects of climate change. However, for the North-east Atlantic, a surface air temperature increase of about 1.5 ºC, a sea level rise of about 0.5 m, and a general increase in storminess and rainfall are predicted by the year 2100. Model results suggest an increase in surface temperature and precipitation in Scandinavia, and a decrease in Arctic ice volume leading to unpredictable reactions of the climate system. Problems associated with sea level rise mainly concern the Dutch and Belgian coastal zone, the Wadden Sea, the German Bight, south-eastern England, and the mid-Channel ports in England and France.

The effects of climate change on the marine ecosystem and on some human activities could be enormous, particularly if changes were to occur in global oceanic circulation patterns. The uncertainty about the occurrence and the possible impacts of such events is very large. Consequently, there will be a need to minimise such uncertainty. To this end, long term monitoring of key physical, chemical, and biological variables and further development of models and assessment tools will be important. Ongoing consideration of the possible changes resulting from climate change and the various possible response scenarios of the North Sea riparian states will need to be coupled with such monitoring and modelling efforts in order to inform the debate on how best to address the future challenges in this important area of concern. As climate change is considered to be at least partly caused by human activities, reduction of the input of greenhouse gases, according to the UN Framework Convention on Climate Change, is necessary.

CLASS A: HIGHEST IMPACT

6.2.2 Category fisheries

Changes and evaluation of impact

Effects of fisheries, including industrial fishing and shellfisheries, occur at all levels in the ecosystem (from benthos to mammals). The main impacts of fisheries vary

Table 6.1 Priority classes of human pressures.

Class*	Human pressure	Category
A	Removal of target species by fisheries	fisheries
	Inputs of trace organic contaminants (other than oil and PAHs) from land	trace organic contaminants
	Seabed disturbances by fisheries	fisheries
	Inputs of nutrients from land	nutrients
	Effects of discards and mortality of non-target species by fisheries	fisheries
	Input of TBT and other antifouling substances by shipping	trace organic contaminants
B	Input of oil and PAHs by offshore oil and gas industry	oil and PAHs
	Input of oil and PAHs by shipping	oil and PAHs
	Input of other hazardous substances (other than oil and PAHs) by offshore oil and gas industry	other hazardous substances
	Inputs of heavy metals from land	heavy metals
	Inputs of oil and PAHs from land	oil and PAHs
	Introduction of non-indigenous species by shipping	biological impacts
	Input of other hazardous substances (other than oil, PAHs and antifouling) by shipping	other hazardous substances
	Introduction of cultured specimen, non-indigenous species and diseases by mariculture	biological impacts
	Inputs of microbiological pollution and organic material from land	biological impacts
C	Input of litter specific to fisheries	litter and disturbance I
	Physical disturbance (e.g. seabed, visual, noise, pipelines) by offshore oil and gas industry	litter and disturbance I
	Input of litter by shipping	litter and disturbance I
	Dispersion of substances by dredging and dumping of dredged material	dredging and dumping
	Dumping of (chemical) ammunition by military activities	dredging and dumping
	Constructions in the coastal zone (incl. artificial reefs) by engineering operations	engineering operations
	Input of chemicals (incl. antibiotics) by mariculture	mariculture
	Mineral extraction (e.g. sand, gravel, maërl) by engineering operations	engineering operations
	Input of nutrients and organic material by mariculture	mariculture
	Physical disturbance by dredging and dumping of dredged material	dredging and dumping
	Inputs of radionuclides from land	radionuclides
D	Physical disturbance (e.g. noise, visual) by shipping	litter and disturbance II
	Input of litter by recreation	litter and disturbance II
	Physical disturbance (e.g. seabed, noise, visual) by military activities	litter and disturbance II
	Physical disturbance (e.g. noise, visual) by recreation	litter and disturbance II
	Power cables (electromagnetic disturbances) by engineering operations	litter and disturbance II
	Dumping of inert material (e.g. wrecks, bottles)	litter and disturbance II

* Human pressures are ranked according to their relative impact on the Region II ecosystem, including sustainable use. While the division in the four classes A-D was established firmly, ranking within classes was not considered to be significant. Class A = highest impact; Class B = upper intermediate impact; Class C = lower intermediate impact; Class D = lowest impact.

from one type to another, but in general are: removal and discarding of target species; seabed disturbance; discarding and mortality of non-target species. These impacts are widespread and are ecologically important.

The removal of target species impacts the whole North Sea to varying degrees. At present, 30 – 40% of the biomass of commercially exploited fish species in the North Sea is caught each year. Despite some recovery in recent years, there is concern about the stocks of herring and cod, which are outside Safe Biological Limits. The spawning stock of mackerel has not yet recovered since its collapse in the mid-1960s. Other stocks including haddock, whiting, saithe, plaice and sole are also close to or outside 'Safe Biological Limits'. Catch levels for many fish stocks are almost certainly not sustainable. Stocks of sandeel and Norway pout are probably within safe biological limits. High fishing mortality of sandeels has been documented to interfere with the food requirements of seabirds off the Scottish coast. These complex interactions call for the development of a multi-species approach. Fishing mortality typically leads to a smaller proportion of older and larger individuals in the population, and it can also affect the genetic composition of a population. Fast growing individuals tend to be selectively removed from the population and this may lead to a smaller size and lower age of maturation. There are indications that this happens with North Sea cod and plaice. Target species play an important role in the food chain of the North Sea. Reduction in the stocks of target species leads to a reduction of food availability for some species but will, on the other hand, decrease the predation pressure on other species. Such interactions can alter the composition of the total fish population.

Seabed disturbance is caused by towed demersal gear, notably beam trawls. Demersal fishing occurs throughout the North Sea but its distribution is patchy. Of the total beam trawl effort, 80% is conducted by the Dutch fleet covering about 40% of the area between the Shetland Islands and Hardanger Fjord, and the Strait of Dover. Other investigations show that some areas are visited more than 400 times a year and some not at all. 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 tides, or for years in the deeper areas. Disturbance of the seabed increases the resuspension of sediments and alters the structure of both soft and hard substrates. Disturbance by demersal gear, including in some areas gear used for catching shellfish, affects biogenic structures that provide a habitat for many organisms, e.g. mussel beds, cold water coral and *Sabellaria* reefs and seagrass beds. Changes in habitat structure are followed by changes in species assemblages.

Various effects are associated with discards and with mortality of non-target species by fisheries. Certain fishing practices lead to the discarding of more than half of the weight of all fish species caught and considerable amounts of benthos. In addition, significant amounts of offal from gutting are dumped. Estimates of discarded fish alone (including offal) amount to 0.55 million t, which is quite substantial compared to total annual landings of around 3.47 million t. Several species of scavenging seabirds do profit from these food sources which constitutes one third of their food requirements, and their populations have increased beyond historic levels.

Towed demersal gears kill both infauna and epifauna. The impact is determined by the size and weight of the gear, the type of substrate and the strength of tides and currents. Species composition has changed from larger, more long-lived species to smaller, more opportunistic species. Quantities of prey displaced, damaged or killed by the passage of towed gears are also made available for scavenging fish and other organisms. A number of fish species, mainly slow-growing species with low fecundity (e.g. large ray species) have declined over recent decades and the proportion of large individuals has decreased. Marine mammals and seabirds die as by-catch in gill nets and other fixed nets. More than 7 000 harbour porpoises are thus lost each year which is thought to pose a significant risk to their population.

Effectiveness of measures

Most of the main target fish stocks used for human consumption remain close to or outside safe biological limits. Of these, cod, haddock, whiting, saithe, plaice, herring and mackerel are jointly managed by the EU and Norway. In the North Sea, the main tool for modulating removal rates from these stocks is the Total Allowable Catch (TAC) system with its associated national quotas. However, the TAC system does not restrain the level of actual catches because of discarding, high grading and misreported or unreported landings. This may lead to an overshoot of the TACs and hence to maintenance of removal rates in excess of those required for the sustainable use of the stocks. An additional factor which adds to this problem is the adjustment for socio-economic reasons of some TACs to above the levels advised by ICES. A recent revision of the EU's Regulations on monitoring and control is expected to enhance the observance of TACs.

No system for limiting fishing effort yet exists in the North Sea, apart from certain conditions included in the EU's Multi-Annual Guidance Programme (MAGP). The size of the fleet of the EC Member States has been reduced in accordance with the overall target of MAGP III. This overall reduction, however, was only achieved because some states reduced their fleets beyond their obligations, thus compensating the failure of others. However, this has not resulted in reduced fishing effort because of compensatory increases in fishing efficiency. Within MAGP IV, which is currently in progress, a reduction of either fleet size or fishing activity is accepted as a way to achieve the desired decrease in fishing capacity for some sectors.

The selectivity of fishing gears, notably trawls, employed in the North Sea continues to be insufficient. This widespread phenomenon results in undesirable by-catch and discard levels. A new package of technical measures will become applicable in 2000 in Community waters. This, and the previous package, also includes a definition of closed areas and/or seasons for the protection of juvenile plaice (and hence sole), whiting and haddock (via restrictions on fishing for Norway pout), herring (via restrictions on fishing for sprat) and mackerel. Alternative gears and fishing techniques are being developed to reduce kills of non-target benthic fauna in the trawl path and to eliminate by-catch of non-target organisms such as bottom fauna and mammals. In co-operation with the fishing sector, these alternative techniques will be tested further for their effectiveness at reducing adverse effects and for their catching efficiency.

At present, the European Commission is in the process of widespread consultation within EU Member States on possible revisions to its Common Fisheries Policy. The intention is to achieve required and agreed revisions by or before 2002 but this date is not, for most topics, obligatory.

The effect of the Norwegian discard ban or of any real-time closures instituted by Norway is unmeasured. Due to the discard ban, Norwegian vessels have to leave areas where fish of illegal size or protected species are caught in quantities above the legal by-catch level. Therefore, the discard ban and real time area closures will in principle reduce fishing mortality of undersized fish or protected species.

Various national conservation measures have also been introduced. Examples include restriction of the cockle fishery in the Dutch Wadden Sea and permanent closure of a part of the intertidal area. In the UK, a number of nursery areas for bass have been protected. UK national legislation insists upon the use of more selective gear in all Norway lobster fisheries and some whitefish fisheries. In 1996, Germany temporarily closed an area of the German Bight to all fishing activities in order to protect juvenile cod.

Recommendations

The outcome of the present quality status assessment calls for appropriate management actions by the competent authorities and international bodies. In view of the large impact of fisheries on the North Sea ecosystem, the conclusions of the 1997 Intermediate Ministerial Meeting should be included into the EU Common Fisheries Policy and Norwegian fisheries management policy. In particular, further development of the ecosystem approach and implementation of it and the precautionary approach to fisheries management is an important step in sustaining harvests and ecosystem health. One of the most urgent issues in this process is the further integration of environmental objectives and fisheries policy (5NSC, 1997).

For immediate action and to help facilitate the initiation of this new policy, the following management actions should be considered:

- To ensure sustainability of the major fish stocks, further consideration should also be given to the application of a precautionary approach to fisheries management as defined in 1998 by ICES and implemented for the first time for a range of stocks by the EU Council of Ministers when setting TACs for 1999. The implied reduction in the fishing effort for many stocks should ameliorate the current situation with respect to other biota, habitats etc;
- To this end, reduction of fleet capacity and the associated fishing effort should continue to be pursued both in the EU and in Norway. The objective is to attain stock sizes clearly above safe biological limits and to minimise ecological damage;
- Additional closed areas which protect juvenile fish should be identified, implemented effectively, and their effect on improving recruitment to the fishery should be evaluated;
- Closed areas should also be considered for the protection of specific benthic habitats if identified to be of conservation value, and methods for the effective closure of benthic habitats should be further developed;
- Development and application of fishing gears which reduce or eliminate catches of non-target organisms and habitat disturbance should be encouraged;
- Early consideration should be given to the management of North Sea sandeel fisheries;
- In view of the complex effects of fishing activities on target as well as on non-target species, in a longer term perspective efforts should be made to develop a multi-species approach as a first step towards the ecosystem approach;
- To ensure better integration of fisheries management with more general environmental needs the research base which is needed to underpin the present limited knowledge of the marine ecosystem should be increased.

6.2.3 Category trace organic contaminants

Changes and evaluation of impact

The category of trace organic contaminants has two sub-categories: trace organic contaminants from land (excluding oil and PAHs, which are dealt with in section 6.2.5); organotin compounds and other anti-fouling substances used by shipping.

Inputs of trace organic contaminants from land include all pathways, e.g. riverine, direct, atmospheric, sewage and sludge formerly deposited, and the dumping of dredged material. Sources can be within or outside the OSPAR area, since long-range transport via air and water commonly occurs. Dispersion of trace organic contaminants covers the entire North Sea and recovery times can be long, for some of them of the order of a century. Most of the available trends concern concentrations in biota, mainly fish (liver) and mussel tissue.

In relatively contaminated coastal areas, decreasing levels of the pesticides α- and γ-HCH (lindane) have been observed in biota. Recent experiments have suggested that lindane affects grazing by zooplankton, thereby enhancing phytoplankton growth. Concentrations of HCB, which at present mainly originate from industrial processes and municipal waste incineration, and the pesticide DDT have decreased at most locations. Long after banning DDT, elevated levels were still observed in UK surveys of fish livers from the Forth and Humber estuaries. There is advice against human consumption and restrictions on the sale of fish and shellfish from several Norwegian fjords because of high PCB levels. High concentrations of the pesticide toxaphene were measured in dolphin blubber from the central North Sea.

In general, the extent of the adverse effects of many pesticides on the health of organisms is unknown and, given their extensive use, this is an issue of serious concern.

At present, trends in PCB concentrations are either absent or slowly downward in the North Sea. BRCs in fish liver and mussel tissue were exceeded in some coastal areas and fjords. Although the ecological risks of PCB contamination were recognised more than a decade ago, recovery times appear to be longer than anticipated. There is increasing scientific evidence for the negative effects of PCBs on hormone metabolism and reproduction in harbour seals, although links with decreased resistance to diseases are as yet unclear.

In the case of dioxins, which are mainly formed during production and incineration processes, a limited number of downward trends in concentrations in biota have been observed. The presence of dioxins in several seafood species concur with high levels in sediments found at some Norwegian locations.

The presence of the polycyclic musk fragrances AHTN and HHCB was demonstrated in German coastal waters. The levels of AHTN in the water remained constant, although HHCB levels had increased at some stations. A multitude of other organic compounds, e.g. brominated flame retardants, pesticides such as dieldrin, simazine and atrazine, PCT (polychloroterphenyl, its chemical characteristics being comparable to PCB), benzothiazoles and the cleaning agents octylphenol and nonylphenol ethoxylates (with suspected hormone disruptive capacity), have been measured in water, sediment and biota. In the absence of information on trends and ecotoxicological criteria the significance of these concentrations is not yet clear. However, a survey of fish in UK estuaries revealed distinct oestrogenic effects in some of the populations. Further research is being undertaken. It should be stressed here that an increasing number of man-made compounds are being detected in the North Sea for which ecological effects are largely unknown.

The impact of tributyltin (TBT) from shipping is greatest in harbours, marinas and shipyards, and close to shipping routes. EACs for sediments are exceeded by up to 30 million times in some harbours, necessitating special attention in some cases with regard to the removal and disposal of sediments to avoid dispersing the contamination. Away from the sources, concentrations in water and sediments are often below detection limits, which are close to or even above the EACs, although accumulation of TBT in aquatic organisms and seabirds is encountered, even in remote areas. The most prominent ecological effect of this substance is changes in sexual organs, leading to impaired reproduction in several species of marine snails. In addition, shell thickening has been observed in oysters. The grazing capacity of zooplankton is also affected by low TBT concentrations, with problems similar to those mentioned for pesticides. Marina areas still show evidence of historical contamination. Recovery times may well be in the order of decades. Information on other antifouling substances is limited.

Effectiveness of measures

Although the uses of PCBs have been banned, some measures still need to be implemented. At the third North Sea Conference (1990) and in PARCOM Decision 92/3, it was agreed that by 1995, or by the end of 1999 at the latest, measures should be taken to phase out and to destroy in an environmentally safe manner all identifiable PCBs and hazardous PCB substitutes. Similar measures are provided for in Council Directive 96/59/EC. The absence of major improvements in sediment quality is partly due to turbation of previously deposited, contaminated sediments, which can act as a source.

Following reduction measures on industrial sources of dioxins, concentrations in sediments and seafood close to these sources have decreased significantly, but are still high.

In the Forth estuary, concentrations of HCBs in water decreased owing to reduced effluent discharges.

The target set in PARCOM Recommendation 92/8 to phase out the use of nonyphenol ethoxylates (NPEs) for domestic purposes before 1995 has been met. Progress in meeting the target of phasing out NPEs from cleaning agents for industrial purposes by 2000 has not yet been assessed. As there is no systematic monitoring for NPEs in the marine environment, associated improvements cannot be evaluated.

Few trend studies on TBT are available. These show decreased concentrations owing to the reduction in the use of TBT and the development of new antifouling paints, although TBT concentrations still often exceed safe levels. In general, information on the trends of persistent organic contaminants is very scarce.

Recommendations

Both the fourth NSC and the 1998 OSPAR MMC agreed to move towards the target of cessation of discharges, emissions and losses of hazardous substances by the year 2020 starting with the substances mentioned in Annex 2 (OSPAR List of Chemicals for Priority Action) of the OSPAR Strategy for Hazardous Substances. Although the main policy target is well in place, significant effort is required in order to accomplish this goal, especially for diffuse sources. Establishing a lead country for each priority substance is important for the implementation process within the OSPAR framework.

At present, a dynamic mechanism is being developed as in integral part of the OSPAR Strategy with regard to Hazardous Substances, to select the hazardous substances to be given priority in addition to those already mentioned in Annex 2 of this strategy. In view of the enormous number of substances of possible concern for the marine environment it is essential that this mechanism is finalised as soon as possible. Techniques should be developed for detecting the presence of such substances in the marine environment, including biomarker assays, and identifying their sources and pathways. This may involve one-off surveys by competent laboratories and, where appropriate, the application of biological effects monitoring techniques.

Within the IMO, a mechanism for a general ban on the use of organotin compounds in anti-fouling paints has been decided. The target is to prohibit their application from 2003 and to require the removal of TBT from ships' hulls by the year 2008. Given the serious effects of TBT on snail and bivalve populations, effective implementation of this measure is required. Within the EC the control on other TBT applications has been increased after a revision of the Directive 76/769/EEC.

6.2.4 Category nutrients

Changes and evaluation of impact

The anthropogenic input of nutrients from land and changed nutrient ratios primarily affect the coastal zone. Nutrient related problems are widespread in particular estuaries and fjords, the Wadden Sea, the German Bight, the Kattegat and the eastern Skagerrak. Negative impacts include periodic disturbances of the ecosystem such as oxygen depletion and the subsequent mortality of benthic organisms, as well as changes in the abundance and diversity of the different animal and plant communities, e.g. increased phytoplankton blooms including, occasionally, harmful species. As a result of periodic oxygen depletion in the Kattegat bottom water, fishing for Norwegian lobster has almost ceased in this area. In view of the storage of nutrients in the sediments, recovery times can be of the order of decades.

Effectiveness of measures

The second NSC agreed to aim to achieve, between 1985 and 1995, a substantial reduction of the order of 50% in inputs of phosphorous and nitrogen, into areas where these inputs are likely, directly or indirectly, to cause pollution. The 1995 Progress Report for the fourth NSC indicates that for phosphorus an overall reduction of 50% would be achieved by most countries, whilst for nitrogen the overall reduction was only about 25% mainly due to rather little progress in the agricultural sector.

Since 1985 there has been a significant reduction in the total inputs of phosphorus, but no clearly discernible reduction in riverine inputs of nitrogen to the North Sea. This is primarily due to the poor reduction of the input to the aquatic environment from agriculture. Riverine inputs showed big annual differences related to differences in river flow. No trends were detected over the period 1990–6. However, over the same period the direct inputs of nitrogen decreased by about 30% and those of phosphorus by about 20%, which reflects improvement in sewage treatment. No general trends were noted for atmospheric inputs. Within the EC Council Directive 91/271/EEC concerning urban waste water treatment and Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources are applicable. The 1998 implementation reports on these directives illustrated their rather poor implementation.

In general, nutrient concentrations in coastal waters did not show a significant trend over the last decade. However, along the coasts of the south-eastern North Sea phosphorus levels have significantly decreased since 1989, owing to reduced phosphorus loads from sewage and industry. Model calculations suggest that a 50% input reduction of both nitrogen and phosphorus may yield up to 30 – 45% reduction in eutrophication parameters. Coastal regions will benefit more than the central and northern North Sea. The merit of a 50% reduction in inputs has been illustrated in Danish waters where, in a two year period of low rainfall (1996–7), the ecosystem responded positively to low riverine inputs of nitrogen.

A number of areas under the influence of inputs from land-based sources continue to suffer from eutrophication. However, some improvement with respect to nuisance algal blooms, oxygen depletion and benthos/fish kills has been seen in many areas.

Recommendations

In view of the negative impacts of anthropogenic nutrient inputs over extended parts of the North Sea coastal zones, implementation of the OSPAR Strategy to Combat Eutrophication should be pursued vigorously. An important first step is to take the necessary action to achieve the agreed 50% reduction target, in particular with regard to nitrogen. Efforts should be focused on emissions, discharges and losses from agricultural and urban sources, in particular through enforced application and compliance with the EC Directives 91/676/EEC and 91/271/EEC concerning nitrate and urban wastewater treatment. Further measures should aim at reducing mineral surpluses. In support of the Strategy, efforts should be made to complete the development and application of the classification criteria for establishing the eutrophication status and to evaluate the situation that will exist when the 50% reduction in the inputs of nutrients has been achieved.

Research efforts should focus on qualitative and quantitative links between nutrient enrichment and environmental responses. Emphasis should be placed on the environmental effects of oxygen depletion and on changes in the community structure of planktonic as well as benthic algal species.

CLASS B: UPPER INTERMEDIATE IMPACT

6.2.5 Category oil and PAHs

Three major sources of contamination by oil and PAHs have been considered: land based sources; offshore oil and gas industry; and shipping.

Changes and evaluation of impact

The impact of oil in the marine environment is related to its form, dispersion and degradation and to the sensitivity of the areas affected. Despite the efforts made, overall estimates of oil entering the North Sea are not well established, but the 1993 QSR indicated a range of 86 000 – 210 000 t/yr.

Land-based sources of oil are mainly reflected in riverine inputs and loads directly into marine waters via point source discharges. Although the 1993 QSR indicates a total oil input via rivers and land run off in the range 16 000 – 46 000 t/yr, there are difficulties in obtaining more up-to-date estimates. The only recent data is for the Dutch sector where riverine loads were estimated at 3 430 t in 1995. For direct discharges, the 1993 QSR indicated that oil inputs were in the range of 13 000 – 35 000 t/yr. Except for refineries, which discharge oil to rivers and directly to marine waters, there is no recent data on point source loads of oil from land based sources. Although no systematic assessment has been made, legal and illegal discharges of oil from shipping contribute to the contamination of the North Sea and harbours.

An overwhelming majority of refineries had complied with the measures stipulated in PARCOM Recommendation 89/5 by 1997 and the amount of oil discharged has decreased considerably. The total input was reduced by more than 50% between 1993 and 1997, to inputs of less than 1 000 t, and by more than 90% since 1981, when inputs were just over 9 000 t. Data for the Dutch sector of the North Sea indicate decreased riverine inputs of oil.

Total inputs of oil from the offshore oil and gas industry (475 installations) have decreased from 28 000 t in 1985 to just over 10 000 t in 1997. Approximately two thirds of the input was from discharges of produced water in 1995. Produced water quantities have increased progressively during recent years due to the maturation of oil fields. Inputs of oil from cuttings have progressively decreased owing to replacement of oil based drilling muds or, by water-based and organic-phase drilling fluids (OBF). Since 1996 the discharge of oil based cuttings has ceased.

OSPAR has not established an EAC or BRC for oil. Comparison of effect concentrations derived from laboratory tests and oil concentrations near drilling sites predicts persistent effects on benthic communities within 200 m of the source. In field surveys, major changes have been found up to 1000 m from the source. The faunal effects can extend to 3 km or more. Elevated levels of hydrocarbons in sediments can be found up to 8 km from some oil fields. With the present numbers of installations, the area potentially affected may be substantial. No trends in oil concentrations could be established.

The amount of oil discharged into the North Sea from shipping was estimated at 6 750 t in 1995. Oil spills predominantly originate from shipping accidents. Accidents such as that involving the ‘Braer’ (1993, 86 300 t) can occasionally cause large releases of oil. Impacts of accidents such as that involving the ‘Pallas’ (1998) can be significant, due to local (e.g. Wadden Sea) and seasonal (overwintering of seabirds) factors, even though the release of oil is relatively small in quantity. Operational discharges of oil are much more frequent than accidental ones. Cumulatively, they may have a greater impact on the environment. However, there are international standards which, if followed, should prevent such discharges creating oil slicks. Since 1989 the number of oil slicks observed in a year has decreased markedly, although recent data suggest increased frequencies in offshore areas. Many of the spills from shipping may go unnoticed. Each year tens of thousands of seabirds die from oiling. However, the consequences for seabird populations are largely unknown. Relatively constant, high oiling rates are found along the Danish West Coast. In the other observed regions of the North Sea, including the Danish part of the Wadden Sea and along the Dutch coast, bird oiling rates appear to be declining.

Inputs of PAHs are related to sources on land, the offshore industry, and shipping, but respective loads are not known. PAHs are widespread, particularly in sediments, including those in offshore areas. No significant reduction in sediment PAH concentrations in the Dutch coastal and the Wadden Sea areas were found. In some highly contaminated areas, decreasing levels in biota have been observed for PAHs (fluoranthene, pyrene and benzo[*a*]pyrene). The lower limit of the EAC for pyrene in sediment is exceeded at almost all the locations that are reported on in Chapter 4, but the situation is better for the other PAHs. Background values for water and biota are still under discussion. Liver tumours in North Sea flatfish can be correlated to contamination, especially PAHs, but also to persistent chlorinated hydrocarbons.

Effectiveness of measures

Discharges of oil from refineries were reduced by more than 90% over the period 1981–97. Most refineries meet the OSPAR discharge standard of 5 mg/l total oil, including aromatic compounds, in effluent (PARCOM Recommendation 89/5).

The total input of oil from the offshore oil and gas industry has decreased significantly since 1985, but has stabilised since 1993. Discharges of oil based cuttings have ceased in accordance with PARCOM Recommendation 92/2. Measures to improve produced water quality have been effective, with most discharges meeting the standard of 40 mg/l oil in water (PARCOM Recommendation 86/1). However, the total volume of produced water has, for various reasons, increased significantly and consequently the overall input of oil via this source has progressively increased.

From 1 August 1999 the North West European Waters, including the North Sea, have become a Special Area under Annex I of MARPOL. Thus, discharge of any cargo-related oil from tankers is prohibited, and stricter controls on the discharge of processed bilge water from the machinery space of other ships have been introduced.

Inputs of PAHs from the offshore oil and gas industry will have decreased by virtue of the reduction of inputs of oil. In order to reduce the input of PAHs from land-based sources, application of one-component coal tar coatings on inland ships were phased out from the beginning of 1999 (PARCOM Recommendation 96/4). Also, limit values have been agreed for emissions to air from aluminium electrolysis plants, which should be achieved by the year 2007 (OSPAR Recommendation 98/2). The present assessment, however, shows that concentrations of PAHs in sediments do not follow a clear trend.

Recommendations

The following actions should be considered:

- The establishment of better estimates of oil and PAH inputs from all land based sources;
- The expeditious fulfillment of the objectives of the OSPAR Strategy for offshore oil and gas activities.

With regard to shipping, it is considered desirable to strengthen existing measures to ensure the continued decline in illegal discharges of oil, e.g. the provision of waste reception facilities in ports, a matter currently under consideration by the EC, the development of measures to promote the use of such facilities, and simplifying control and enforcement. The further development of tools to determine sources, e.g. fingerprinting and tagging, should be pursued.

Based on available knowledge of sources and pathways of PAHs, further programmes and measures, e.g. for creosoted timber and wood burning stoves, should be considered and developed as necessary. Moreover, reliable information is needed on concentrations and effects of PAHs in the marine environment.

6.2.6 Category heavy metals

Changes and evaluation of impact

Concentrations in water, sediments and biota decrease from the coast to the open sea. They are highest in estuaries, fjords, and near industrialised zones and densely populated areas. Mean concentrations of cadmium and lead in water have decreased in the North Sea, comparing the periods 1982–5 and 1986–90. This reflects the significant reductions in the inputs of all heavy metals in that period. In most areas, levels of cadmium, mercury, lead and copper in sediments and biota decreased or showed no significant trend, depending on the area. The possibility that some early data sets may have been affected by poorer quality data cannot be discounted, however.

Heavy metals are naturally occurring and do not degrade. Anthropogenic contributions may cause serious effects. There is evidence of local effects close to known sources, but no evidence of widespread toxic effects. Effects on biota can be expected in areas where EAC limits (in sediments and water) are exceeded, especially if the observed concentrations are higher than the upper EAC limits. Such areas have been observed for the water and sediment compartments. It must be noted here that only provisional EACs exist for heavy metals in sediments, while EACs for biota are still lacking.

Most reported cadmium levels in seawater are within the EAC range, except for the most contaminated locations in some estuaries, where the EAC upper limit is exceeded or approached. Mercury levels in seawater seldom exceed the EAC lower limit, and lead concentrations are generally below the EAC values.

Reported levels of lead in sediments are within the EAC range or even exceeded the EAC upper limit. For the other metals, the EAC upper limit in sediment is exceeded in some estuaries and in some locations in the Dutch Wadden Sea (cadmium). In addition, concentrations of metals in sediments have been reported to exceed the EAC lower limits in a much larger area, in some locations in the German (cadmium), Dutch (cadmium and copper) and Belgian (cadmium, mercury and copper) coastal zones.

BRCs for cadmium, mercury, lead and copper in biota, i.e. blue mussels, are exceeded in some estuaries, fjords and along the south-eastern coast of the North Sea. For example, the BRC for cadmium in blue mussels is exceeded 95-fold in the Sørfjord and 20-fold in the Hardangerfjord, due to the presence of smelting industries. In the Sørfjord, advice against the consumption of blue mussels, because of high metal concentrations (cadmium and lead), has been issued. The levels of mercury in fish muscle exceed BRCs at some locations along the east coast of the North Sea.

Ecological risks mainly concern the marine life in estuaries and in the coastal zone. Some of these areas where heavy metal concentrations are highest may also be of major ecological importance as habitats, breeding and feeding grounds for numerous species. Cadmium, mercury and lead accumulate in organisms at any trophic level and end up in top predators (fish, birds, sea mammals or even man), while copper can affect the phytoplankton species composition and its productivity.

Recovery times are in the order of decades. Dissolved metals are transported with the water masses and remain for 1 – 3 years in the North Sea. Most of the particulate bound metals, however, are trapped in sedimentation areas where they pose a risk to benthic organisms. Even metals bound to buried sediments may become available by resuspension and mobilisation.

Effectiveness of measures

Policy measures have resulted in important reductions in the atmospheric deposition of cadmium, mercury and lead, in riverine inputs of mercury and in direct inputs of cadmium, mercury, lead and copper. Most countries have reached, or are close to, the reduction target of 50% set for the period 1985–95. In some areas with a high sedimentation rate and in estuaries, fjords and enclosed seas which are more exposed to contamination, these reductions have led to lower levels of cadmium, mercury, lead and copper in sediments. Cadmium and lead concentrations in water, and mercury levels in biota have decreased in most areas of the North Sea. Major reductions at sources and in concentrations have been achieved.

Recommendations

Previous input reduction measures for heavy metals have proven effective to some extent. Despite these achievements, cadmium, mercury and lead should still remain substances for priority action under the OSPAR Strategy with regard to Hazardous Substances. Effective implementation of the recommendation to phase out mercury-based processes of the chlor-alkali industry should be pursued. No OSPAR recommendations have yet been issued for copper. Since this metal mainly comes from diffuse sources and as it is used in anti-fouling substances as an alternative for TBT and tar, consideration of appropriate measures is recommended.

This quality status report shows that specific measures should be developed at the appropriate level to solve regional and local problems.

6.2.7 Category other hazardous substances from sea-based sources

Changes and evaluation of impact

Inputs of hazardous substances, other than oil, PAHs and anti-fouling substances, are considered from two sources: the offshore oil and gas industry and shipping.

The main inputs of hazardous substances from the offshore oil and gas industry arising from produced water (and formerly in oil-based muds) and from flaring operations, comprise benzene, added chemicals, phenols and benzoic acids. Barium and iron are the most dominant elements, but smaller amounts of other metals are also found, especially nickel, lead and zinc. Although concentrations of contaminants in produced water can be estimated, available information is too limited to make an assessment of impacts on environmental quality and ecosystem effects. Increasing oil production and ageing of the oil fields are reasons for growing concern. This is because quantities of produced water will increase and associated discharges of hazardous substances are expected to increase further.

Shipping causes input of hazardous substances through cleaning tanks, burning fuel that contains waste products, discharges of waste and loss of cargo. A variety of substances enter the environment, e.g. phosphorus ore, pesticides, lipophilic substances. Discharges of the latter group of substances are permitted in some cases, but have caused the death of many seabirds along the Dutch coast.

Effectiveness of measures

Between 1996 and 1998 a number of decisions were adopted by OSPAR in order to regulate discharges of waste and chemicals from offshore installations, and in 1999 OSPAR adopted its Strategy on Environmental Goals and Management Mechanisms for Offshore Activities. In 1995, PARCOM adopted a ‘harmonised offshore chemical notification’ format (HOCNS) to facilitate the control of chemicals used and discharged offshore. Additionally, a procedure has been put on trial, which provides a means of assessing chemicals according to their hazard ranking. Together, these procedures have enhanced national control measures and promoted the principle of substitution whereby more hazardous chemicals are replaced by those which are less hazardous.

Within the framework of IMO, several measures have been taken in order to reduce pollution to air and water from ships and to reduce further the risk of shipping accidents, including routeing measures. Furthermore, measures were taken to reduce the number and quantity of illegal discharges more effectively, and to increase the safety of shipping traffic. Within the Bonn Agreement Contracting Parties adopted the FEPO (Facilitating Effective Prosecution of Offenders) Manual as a means to improve and facilitate the effective prosecution of offenders against MARPOL. The second part of the Manual on Oil Pollution containing guidelines on international co-operation was adopted on 1 October 1999. These guidelines are a step forward in the regional implementation and enforcement of the MARPOL regulations.

Recommendations

Although the offshore oil and gas industry and shipping are two of the main activities in the North Sea, the information which is currently reported within OSPAR only allows limited scope for assessment of the impact of hazardous substances mentioned in this section. More information is needed on current and potential inputs, field concentrations, chemical fate and biological effects of such substances. Co-operation and the exchange of all relevant information, in line with the EC Council Directive 90/313/EEC on 'freedom of access to environmental data', is required. Active dissemination of information to the general public through a variety of means (e.g. publication of reports, information to press, web-sites) is of key importance for increasing public awareness and understanding by all stakeholders. To this end, reporting efforts within OSPAR should be reinforced and actions should be considered.

With regard to the offshore industry, effective implementation of the OSPAR Strategy on Environmental Goals and Management Mechanisms for Offshore Activities should be pursued.

With regard to shipping, actions such as the following should be considered:

- Ratification and effective implementation of various international agreements, such as Annex VI to the MARPOL. The EU Directive on Harbour Reception Facilities, which is currently being developed, should be a major step forward in the reduction of waste discharges;
- Measures to recover lost cargo, e.g. tags and transponders, should be promoted in international forums and could be beneficial from both an ecological and an economic point of view;
- International co-operation on control, enforcement, cost claims and sanctioning should be further strengthened;
- Positive economic incentives delivering environmental benefits should be developed.

6.2.8 Category biological impacts

Changes and evaluation of impact

The importance of biological impacts is mainly due to the high potential risks of diseases, changes of species composition, the introduction of toxic algal species and genetic changes in indigenous fish populations.

Non-indigenous species can spread out over large areas and ecosystem recovery may be impossible. Several activities may lead to an introduction of organisms, such as: the introduction of non-indigenous species by shipping; introduction of cultured specimens, non-indigenous species, diseases and parasites by mariculture; and inputs of microbiological pollution from land.

Ballast water is one of the main vectors for the introduction by shipping of non-indigenous species into the North Sea. Alternatively, organisms may be transported while attached to the hull of a ship. Throughout history, several species are known to have been introduced by shipping, e.g. the North American razor clam, and a polychaete (worm) species. Some of the newcomers, e.g. Japanese seaweed, appeared to have deleterious effects in their new environment by outcompeting indigenous species, while in other cases no adverse effects have been demonstrated. However, observed examples (e.g. in the Mediterranean) show that these risks should not be underestimated.

An example of an introduction of non-indigenous species by mariculture is the toxic alga *Fibrocapsa japonica.* This planktonic species has been observed in the entire Dutch coastal zone and in the German Wadden Sea. Its toxin appears to accumulate through the food chain, as fibrocapsine has been demonstrated in dead seals. A growing concern is human consumption of shellfish containing algal toxins, which may affect public health.

Introduction and escape of cultured specimens may cause changes in the genetic composition of wild stocks. The number of escapees may well contribute to a loss of genetic diversity and reduce the ability of wild salmon stocks to adapt to local environmental conditions. The extent of such effects on genetic composition is not well documented.

It has been shown that antibiotic resistance in bacteria evolves near fish farms. However, use of antibiotics has reduced significantly in recent years due to the development of effective vaccines.

Spreading of salmon lice from farmed to wild stocks of salmon is an issue of concern in the northern part of the region (especially in Norway). Heavy infection may cause large mortality and it appears that the problem with salmon lice has increased. The detailed mechanisms for transfer of lice from cultured to wild salmonids is not well documented. Infections, however, have been found to be heavier in regions with dense aggregation of aquaculture plants.

The microbiological quality of bathing water, which mainly depends on inputs of microbiological pollution from land, has improved in recent years due to the wider use and improvement of waste water treatment plants. A significant increase in the number of satisfactory locations was observed. However, bacteriological pollution from insufficiently treated sewage and from various diffuse sources remains an issue of concern along the shorelines of the North Sea.

Samples of shellfish are tested regularly in order to check the extent to which they are contaminated by *E. coli.* This determines whether the shellfish can go directly for human consumption or are required to be treated beforehand (Shellfish Hygiene Directive (91/492/EEC)).

Effectiveness of measures

In order to reduce the risk of introducing non-indigenous species, ballast water may be exchanged in open sea, although this can be hazardous and is not always possible for ships, depending on their design and the prevailing sea conditions. Within regional areas such as the North Sea this measure may not be effective in preventing the introduction of viable new species and would not often be practicable given the short voyage times. The IMO has published guidance on minimising the risk of introducing non-indigenous species, and this is widely available to the shipping industry. The IMO is currently developing draft regulations on ballast water management, although it is likely to be several years before such measures might come into force.

The EC Directive on urban waste water treatment (91/271/EEC) regulates treatment of sewage effluents. This directive must be implemented by 1999 to 2006, depending on the size of the agglomeration. Also, the EC Directive on the quality of shellfish waters (79/923/EEC) plays a significant role in protecting shellfish fisheries from sewage pollution.

Recommendations

The risk of introducing non-indigenous species during transit between continental shelf ports should be taken into account during the development of any regional guidelines for ballast water management. As differences in regulations between neighbouring ports could lead to undesirable economic effects, both the ecological and economic consequences of regional agreements should be considered. OSPAR Contracting Parties should take concerted action within the IMO in order to support and speed up the IMO's ongoing work on regulations for ballast water management. North Sea riparian states should consider the need for special regulations for the North Sea (or the North West European Waters).

As it is often not clear whether species found in ballast water are indigenous or non-indigenous, a comprehensive study is needed to determine the indigenous species for each of the riparian OSPAR states.

There is a need for more research on possible genetic effects of cultured salmon on wild stocks. Information about the spreading of parasites and diseases related to mariculture activities is also very limited and more research is needed.

In order to avoid health risks arising from the consumption of shellfish, continued effective monitoring of algal toxins is required. Monitoring of both water and shellfish flesh is already a requirement of the EC Directive on the quality of shellfish waters in order to prevent shellfish which are affected by toxins from being harvested and sold.

6.3 Limitations in knowledge

The assessment of the marine environment does not only suffer from gaps in knowledge, but also from incomplete understanding of the complexity of nature with synergisms and non-linear impacts. This, coupled with an absence or lack of fully developed assessment tools, often presents difficulties for the assessment of the impact of human activities. In the present section, key limitations in knowledge are listed. Some gaps in information are a consequence of earlier priorities, both in terms of geographical coverage and the range of substances and issues.

Climate change

In order to decrease the uncertainty about the occurrence and impact of climate variability on the marine environment, long term monitoring of key physical, chemical, and biological variables and further development of models and assessment tools is essential.

Contaminants and nutrients

It is recognised that the OSPAR riverine inputs and direct discharges (RID) programme of monitoring and reporting on the annual inputs of heavy metals, nutrients, PCBs and lindane provides a basic set of relevant data. The following points relate, therefore, to those contaminants not covered by the RID programme, or aspects of substances that are not adequately addressed by annual RID estimates alone:

- The lack of data on organic hazardous substances is very apparent. First of all there are analytical difficulties and insufficient commitment to funding the effort needed to establish the required detection limits. Secondly, further intercalibration and harmonisation of procedures is needed in order to generate reliable and comparable data sets. In addition, OSPAR failed to take up some of the proposed one-off surveys for specific compounds, e.g. pesticides. Contracting Parties therefore should take concerted action, for example by means of one-off surveys, to deal with hazardous organic substances which reach the marine environment;
- Consistent information on inputs, environmental concentrations and biological effects of chemicals from some sectors, such as the offshore industry, shipping and agriculture, should have been more easily available for the present assessment;
- The chronic and combined effects that hazardous substances have on organisms are not well known, which seriously hampers the assessment of their environmental risk. Endocrine disruption is one of the issues of emerging concern. More information is needed on the substances that affect the hormone systems of organisms, their effect concentrations and ecological impacts;

- Reliable quantitative information on sources and inputs of nutrients is needed. In addition, our understanding of the interrelationship between nutrient sources and eutrophication, and the influences of seasonal variations should be further improved. This will benefit the development of predictive tools for assessing with less uncertainty and greater reliability the direction and relative magnitude of human impacts;
- Trend monitoring in the OSPAR area is unsatisfactory due to insufficient quality assurance procedures and commitment to monitoring;
- There is a lack of data on inputs and fluxes of substances, which are important for establishing budgets for assessment purposes. Reliable estimates of inputs from the atmosphere and sources such as the seabed, adjacent seas etc. are especially needed. In general, a more holistic approach is required;
- A lot of existing data are either not available or not communicated, which is primarily a problem of accessibility and organisation.

Fisheries

- Detailed information is available for relatively few species impacted by fisheries;
- Additional spatial and seasonal data and improved models on multi-species interactions are needed, with special emphasis on predator-prey relationships among commercially exploited fish species and other vulnerable species;
- More information is needed on the longer-term impacts of demersal fisheries on the physical and biological environment of the sea bed. Alternative techniques for demersal fisheries are being developed, though no information on the extent of reduced impacts on bottom fauna and the seabed is available yet;
- Estimates of the seasonal and spatial variability of discards of target and by-catch species from major fisheries should be generated for use in models on the long-term impacts of fisheries.

Other human activities

- Comparable data is lacking on the economic benefits (and drawbacks in the case of misuse of North Sea resources) associated with the North Sea. Such information could improve the scope of a North Sea assessment;
- Information on tourism from different countries is incomplete and is not harmonised, despite being one of the major human activities in the coastal area of the North Sea. Appropriate assessment indicators on tourism could be developed. For instance, one-day visitors are not counted;
- The effect of genetic and ecological interaction of escaped salmon on wild salmon stocks is not well documented. Knowledge is also limited on the extent to which cultured salmon contribute lice to wild salmon and the risk of diseases spreading from mariculture to wild stocks.

Assessment tools

- OSPAR has applied sets of values to assess environmental concentrations, i.e. BRCs to compare with reference sites and EACs to integrate biological effects and chemical analyses. As these reference values are shown to be important for a correct assessment, the data sets need to be completed and updated, with special emphasis on persistent organic compounds. Furthermore, it would be necessary to improve EACs so that assessments can take into account the problems of chronic and combined effects of chemicals;
- Under the new Annex V of the OSPAR Convention, concerning the protection and conservation of the ecosystems and biological diversity of the maritime area, the Commission will aim to apply an ecosystem approach. In this context, Ecological Quality Objectives (EcoQOs) can play an important role. Work is being done to develop such objectives for the North Sea as a test case, incorporating both scientific knowledge and political deliberation. If this test case is successful it might form the basis for further use of EcoQOs. They could also be considered as an important tool in the classification of the ecological status within the EC Water Framework Directive.

Problems of regional intercomparability

The North Sea can by no means be regarded as a closed system. Its physical, chemical and biological properties are strongly influenced by the variable water exchanges with the neighbouring ocean and seas, the countries in its catchment area, and the atmosphere. As has been pointed out above, knowledge of budgets and fluxes is important for assessing the chemical status of the North Sea. This does not only require harmonisation of the monitoring effort, chemical analyses and data handling within the North Sea area, but also with the other OSPAR regions and the EU. Similar problems apply to the assessment of other human pressures, which are often transboundary in nature, e.g. shipping, fisheries, pipelines and cables. Also, assessment of the migration of organisms, both natural and through transportation by man, can be improved by concerted research and monitoring.

The interdependency of the North Sea and neighbouring OSPAR regions will be given further attention in the QSR 2000.

6.4 Overall Assessment

The aim of this section is to consider progress made in the prevention of pollution and the protection of the

Greater North Sea (OSPAR Region II). To this end, consideration is given to the changes that have occurred, building on the information given in the 1993 QSR. Transportation on the North Sea and the exploitation of living and non-living resources are increasing, and some areas, in particular the Norwegian Trench, continue to function as a sink for contaminants. Consequently, the ecosystems continue to suffer from a number of old problems, sometimes showing some signs of amelioration, but also new problems have arisen. The effects of hazardous substances, eutrophication, and the direct as well as indirect impacts of fisheries comprise the most important issues.

Riverine and atmospheric pollution originates mainly from those areas around the North Sea which are densely populated. Parts of the catchment area are heavily industrialised and intensively used for agriculture. The number of people living in this area is large (see *Table 3.1*) and has increased by about 10% compared to the early 1990s.

There is the potential for substantial effects to occur as a result of climatic changes. While both coastal zone ecosystems and human activities may be at risk due to sea level rise and increases in numbers and force of storms, unmanageable effects could occur if large-scale oceanic circulation patterns were to change. This would affect both the marine and terrestrial ecosystems and, obviously, interfere with man's activities. Although indications for this prospect exist, at present science does not allow for an accurate estimation of this risk.

Trends in human impacts

For many issues there have been improvements in environmental status since the 1993 QSR. Inputs of cadmium, mercury and lead have decreased. Estuaries, coastal zones and a very few locations in the sea near some well-known point sources show significant downward trends in concentrations in sediments and organisms. There seem to be generally decreasing trends in concentrations of PAHs and some organochlorines in organisms. There have been major reductions in oil discharges from refineries. Offshore, the discharge of oil from cuttings has ceased. Together, these account for a reduction of the order of 30 000 t/yr of oil entering the rivers and the sea. With respect to nutrients, there have been overall reductions in the inputs of phosphorus (of the order of 50% since 1985). There has been a reduction in the direct inputs of nitrogen (of the order of 30% since 1990) although this represents only a small proportion of the total input. The impact of the huge quantities of dredged material disposed of has decreased due to lower contamination of that material. However, increased capital dredging, needed for accommodating ships with a greater draft, will increase pressures from this activity. Some of this pressure may be mitigated by use of the best available dredging techniques and making use of the dredged material for engineering purposes within the estuary of its origin. Other contributions to the reduction of human pressures since 1993 were the cessation of the dumping of sewage sludge at the end of 1998 (the dumping of other industrial wastes was phased out in 1992) and the reductions in a number of the chemicals used in mariculture.

With respect to some other major human pressures, no general improvement can be reported. Inputs of produced water by the offshore oil and gas industry have increased. Overall inputs of nitrogen have not changed significantly. A number of areas still suffer from eutrophication. However, some improvements have been noted. Fishing continues to have a major impact on the North Sea ecosystems through the removal and discarding of target species, mortality of non-target species and the physical disturbance of benthic habitats. Many target fish stocks are outside Safe Biological Limits. Concentrations of the anti-fouling agent TBT still exceed safe levels in marina areas. 'Imposex' caused by TBT in a number of benthic organisms, is still a common phenomenon in the North Sea, although measures have improved the situation locally.

Coastal zone

In general, human pressures are greatest in the coastal zone as it is the area most immediately affected by waterborne contaminants, nutrients and many human activities. Human impacts in estuaries situated in industrialised and highly populated areas, such as the Seine, Western Scheldt, Rhine/Meuse mouth, Ems, Weser, Elbe, Forth, Humber and Thames, can include health problems for organisms, eutrophication and physical disturbance by dredging. In some Norwegian fjords, which are relatively sensitive to human pressures due to limited water exchange, and at some locations along the Scottish coast, mariculture can be a significant source of contamination. It also introduces diseases, non-indigenous species and escaped cultured fish. At the same time, mariculture is sensitive to contamination and to eutrophication effects, such as oxygen depletion and toxic algae. In many areas which are important as nursery grounds for young fish and sea mammals and as feeding grounds for birds, e.g. the Wadden Sea, fishing and shellfish harvesting conflict with these ecological functions.

Many sensitive coastal habitats in the southern part of the Greater North Sea, such as freshwater/saltwater transition areas, intertidal areas, wetlands and salt marshes, vanish due to draining, erosion or the construction of coastal defence structures or other installations. These coastal zones, in particular the sandy coasts, also tend to be severely disturbed by recreational activities. In addition, pollution of the coast by litter occurs on a large scale.

Although most areas in the coastal zone are relatively well-studied, information on the combined effects of human activities on the ecosystem and on conflicts between human activities is very limited.

Open sea

In the open sea, three main impacts of human activities occur.

Fisheries heavily affect the ecosystem by the regular removal of a large part of the total fish biomass. This activity not only removes food from the system, but also causes substantial mortality to non-target species. Benthic organisms, but also non-commercial fish species, birds and marine mammals are affected.

Inputs of contaminants occur in the open sea from the offshore oil and gas industry, for an important and increasing part through the discharges of produced water. Oil (including PAHs), but also phenolic compounds, possible endocrine disruptors, and chemicals used in the production process are discharged.

Some persistent contaminants also reach high levels in the open sea at the places where they are concentrated, such as sedimentation areas (in particular the Skagerrak and Norwegian Trench), and, in the case of lipophilic trace organic contaminants, in the fatty tissues of living organisms.

Finally, the intensive, sometimes conflicting, use of the North Sea causes a number of problems in relation to a healthy ecosystem and sustainable use.

6.5 Conclusions, outlook and recommendations

"There is hope because of the progress made, but concern because this progress is sometimes slow." (Former chairman of ASMO).

Conclusions

1. Generally, significant improvements can be reported in connection with the inputs of heavy metals, oil and the nutrient phosphorus. These improvements are predominantly reflected in the reduced pressure on the marine environment at a local or regional level. At the same time, an increasing number of man-made compounds are being detected in the North Sea for which the ecological effects are largely unknown.

2. Some improvements have been made with respect to TBT but existing levels are still a matter of concern. The situation will become more satisfactory once less hazardous anti-fouling coatings are introduced on a much larger scale than at present.

3. The inputs of some persistent organic substances have been reduced, but corresponding reductions in concentrations are not often observed in the marine environment. Further improvements are required. In general, the extent of the impact of many hazardous substances is unknown and, where there is significant use and pathways to the marine environment, such substances are of serious concern.

4. Certain activities give cause for concern because of their continued widespread impact or increasing trend. These include:

- impacts of fisheries by the removal and discarding of target species, seabed disturbance, and discards and mortality of non-target species;
- inputs of nitrogen from land-based sources;

inputs of oil and production chemicals to the marine environment from offshore oil and gas exploitation.

5. Dredging impacts have diminished because of the reduced contaminant load in the large quantities of material which are disturbed. Accommodating larger vessels will increase the quantity of dredged material and thus this human pressure.

6. The tools available for assessment are limited in their development and range of application. There is a need to improve the means of assessment and, to this end, to optimise and integrate the biological effects and chemical analysis approaches to monitoring and assessment.

7. There are (inevitably) gaps in knowledge. These relate both to the systematic spatial coverage of conditions in the Greater North Sea and to temporal trends. It should be noted however, that the complexity of natural systems with synergisms and non-linear impacts will always interfere with interpretation and assessment of data.

Outlook

1. The general improvements that have been made until now are reassuring and the five OSPAR strategies provide a framework for continuing these improvements. However, there is an urgent need to develop the measures necessary for their implementation, in order to meet their objectives and time scales.

2. Pressures associated with fisheries will, if the activity is not limited, assume a greater (relative) importance in terms of adverse impact.

3. Whilst some aspects of offshore oil and gas activity have improved considerably, there is likely to be an increase in the quantities of produced water discharged containing oil and production chemicals. This is due to the progressively maturing oil fields and the increasing production of oil and gas.

4. The significant increase anticipated in the size of cargo vessels using North Sea ports will result in additional physical disturbance with increased capital dredging in the short term.

5. With increasing space requirements in densely populated coastal areas and improving technical knowledge, more intensive use of the marine area can be expected. Spatial planning and integrated management, e.g. for artificial islands and offshore windmill parks, will become increasingly important in order to prevent conflicts between new and existing human activities and to protect marine and coastal habitats.

6. The major changes and impacts which could arise through rising sea levels and the increased severity of storms associated with global warming could cause effects far exceeding those caused by other human pressures, but they would be on a longer time scale. Should sea levels rise as predicted, the resulting coastal protection measures and possible land retreat will have significant impacts in the medium to long-term.

Recommendations

These recommendations complement the more detailed recommendations made in section 6.2. By their nature they are more general, or relate to matters common to several aspects of this QSR. The following actions and those described in section 6.2 should be considered by the appropriate authorities:

1. The OSPAR Strategies should be implemented, in line with their respective time scales for action, in order to ensure continuing improvements. To this end, adequate resources should be made available.

2. Future assessments of the quality status of the North Sea could benefit from improved co-operation with other fora on a European and even global scale, especially with regard to harmonised monitoring effort, data exchange and development of compatible assessment tools.

3. An overview of existing information and literature should be established in particular regarding the occurrence and effects of hazardous substances in the marine environment. Steps should be taken to close the gaps in knowledge and there is a need to concentrate effort on particular issues of concern. In respect of temporal trends and spatial surveys, monitoring efforts should be optimised within the JAMP.

4. Effort should be invested in developing tools for the assessment of substances and effects of concern, taking into account the merits of integrating biological effects and chemical monitoring approaches. Further development of biomarker techniques and more efficient data gathering is crucial, e.g. by one-off surveys by a pilot laboratory.

5. Given that some human pressures, or aspects of them, are likely to increase in the short term or are unlikely to diminish (cf. Outlook), the need for consideration of their impact should be reviewed in the short term and action taken accordingly.

6. On the basis that the possible changes associated with global warming will increasingly assume greater importance in the medium to long-term, the implications on the North Sea environment of those changes should be evaluated.

7. The ecosystem approach, which has been a major recommendation of the 1997 IMM, needs further development and application according to OSPAR's Annex V. An important aspect of this approach is improved integration between the different sectors operating on the sea, but also between scientists, policy makers and other stakeholders. Through concerted action these parties should progress towards effective protection and conservation of the ecosystems and biological diversity of the maritime area.

8. In order to increase understanding by all the stakeholders and by the general public of the human influence on the marine environment and the related policies, dissemination of information should be actively pursued by a variety of means (e.g. publication of reports, information to the press and web-sites).

SPECIES

Reference list of species mentioned in this report (sorted by common (English) name within categories)

Common (English) name	Scientific name
Mammals	
Bottle-nose dolphin	*Tursiops truncatus*
Common dolphin	*Delphinus delphis*
Common seal	*Phoca vitulina*
False killer whale	*Pseudorca crassidens*
Fin whale	*Balaenoptera physalus*
Grey seal	*Halichoerus grypus*
Harbour porpoise	*Phocoena phocoena*
Killer whale	*Orcinus orca*
Long-finned pilot whale	*Globicephala melaena*
Minke whale	*Balaenoptera acutorostrata*
Risso's dolphin	*Grampus griseus*
Sperm whale	*Physeter macrocephalus*
White-beaked dolphin	*Lagenorhynchus albirostris*
White-sided dolphin	*Lagenorhynchus acutus*
Birds	
Black guillemot	*Cepphus grylle*
Black-headed gull	*Larus ridibundus*
Black scoter	*Melanitta nigra*
Common coot	*Fulica atra*
Common gull	*Larus canus*
Common tern	*Sterna hirundo*
Curlew	*Numenius arquata*
Eider duck	*Somateria mollissima*
Gannet	*Sula bassanus*
Goldeneye	*Bucephala clangula*
Great skua	*Catharacta skua*
Greater black-backed gull	*Larus marinus*
Grebes	*Podiceps* sp.
Guillemot	*Uria aalge*
Herring gull	*Larus argentatus*
Kentish plover	*Charadrius alexandrinus*
Kittiwake	*Rissa tridactyla*
Lesser black-backed gull	*Larus fuscus*
Little auk	*Alle alle*
Little tern	*Sterna albifrons*
Mallard	*Anas platyrhynchos*
Northern fulmar	*Fulmarus glacialis*
Northern gannet	*Morus bassanus*
Oystercatcher	*Haematopus ostralegus*
Puffin	*Fratercula arctica*
Razorbill	*Alca torda*
Red shank	*Tringa totanus*
Red-breasted merganser	*Mergus serrator*
Shag	*Phalacrocorax aristotelis*
Shelduck	*Tadorna tadorna*
Swan	*Cygnus* sp.
Tufted duck	*Aythya fuligula*
Velvet scoter	*Melanitta fusca*
Fish	
Anglerfish	*Lophius piscatorius*
Arctic char	*Salvelinus alpinus*
Brill	*Scophthalmus rhombus*
Cod	*Gadus morhua*
Dab	*Limanda limanda*
Eel	*Anguilla anguilla*
Flounder	*Platichthys flesus*
Haddock	*Melanogrammus aeglefinus*
Halibut	*Hippoglossus hippoglossus*
Herring	*Clupea harengus*
Horse mackerel	*Trachurus trachurus*
Lemon sole	*Microstomus kitt*
Mackerel	*Scomber scombrus*
Megrim	*Lepidorhombus whiffiagonis*
Mullet	*Crenimugil labrosus*
Norway pout	*Trisopterus esmarki*
Plaice	*Pleuronectes platessa*
Rainbow trout	*Oncorhynchus mykiss*
Ray	*Dasyatis* sp.
Round-nose grenadier	*Coryphaenoides rupestris*
Saithe	*Pollachius virens*
Salmon	*Salmo salar*
Sandeel	*Ammodytes* sp.
Sea trout	*Salmo trutta*
Sea bass	*Dicentrarchus labrax*
Skate	*Raja batis*
Skate	*Raja sp.*
Sole	*Solea solea*
Sprat	*Sprattus sprattus*
Spurdog	*Squalus acanthias*
Starry skate	*Raja radiata*
Thick-lipped grey mullet	*Crenimugil labrosus*
Thornback ray	*Raja clavata*
Turbot	*Psetta maxima*
Whiting	*Merlangius merlangus*
Witch	*Glyptocephalus cynoglossus*

Common (English) name	Scientific name
Lower animals	
Amphipod	*Corophium volutator*
Auger shell	*Turritella communis*
Bivalve mollusc	*Tellimya ferruginosa*
Blue mussel	*Mytilus edulis*
Brittlestar	*Amphiuridae*
Brittlestar	*Ophiuroida*
Brown shrimp	*Crangon crangon*
Thick trough shell	*Spisula solida*
Clam	*Spisula subtruncata*
Clams	*Spisula* sp.
Cockle	*Cerastoderma edule*
Common shore crab	*Carcinus maenas*
Common whelk	*Buccinum undatum*
Common winkle	*Littorina littorea*
Crawfish	*Palinurus* sp.
Cumacean	*Eudorella emarginata*
Cumacean	*Pseudocuma longicornis*
Dead man's fingers	*Alcyonium digitatum*
Dog whelk	*Nucella lapillus*
Edible crab	*Cancer pagurus*
Great scallop	*Pecten maximus*
Hermit crab	*Eupagurus* sp.
Horse shoe worm	*Phoronis* sp.
Lobster	*Homarus gammarus*
Lugworm	*Arenicola marina*
Masked crab	*Corystes sp.*
Native/flat oyster	*Ostrea edulis*
Northern prawn	*Pandalus borealis*
Norway lobster (Dublin Bay prawn)	*Nephrops norvegicus*
Ocean quahog	*Arctica islandica*
Pacific oyster	*Crassostrea gigas*
Polychaete worm	*Lanice conchilega*
Polychaete worm	*Machellona* sp.
Polychaete worm	*Marenzelleria* sp.
Polychaete worm	*Nephtys* sp.
Polychaete worm	*Nereis* sp.
Polychaete worm	*Owenia fusiformis*
Polychaete worm	*Pectinaria* sp.
Polychaete worm	*Sabellaria* sp.
Razor clam	*Ensis directus*
Red whelk	*Neptunea antiqua*
Scallop	*Placopecten* sp.
Sea mouse	*Aphrodita aculeata*
Sea urchin	*Brissopsis lyrifera*
Sea urchin	*Echinocardium* sp.
Sea urchin	*Psammechinus miliaris*
Smooth artemis	*Dosinia lupinus*
Spider crab	*Maja squinado*
Striped venus	*Chamelea gallina*
Surf clam	*Spisula solidissima*
Tellin	*Abra alba*
Tellin	*Abra* sp.
Tellin	*Tellina fabula*
Trough shell	*Mactra corallina*
Velvet crab	*Liocarcinus puber*
Wedge shell	*Donax vitali*
Plants	
Bladder wrack	*Fucus vesiculosus*
Eelgrass	*Zostera marina*
Eelgrass	*Zostera noltii*
Ginger	*Hedychium gardeneri*
Japanese seaweed	*Sargassum muticum*
Knotted wrack	*Ascophyllum nodosum*
Kelp	*Laminaria digitata*
Kelp	*Laminaria hyperborea*
Maërl	*Lithothamnion* sp.
Micro alga	*Chattonella antiqua*
Micro alga	*Chattonella marina*
Micro alga	*Chattonella verriculosa*
Micro alga	*Chrysochromulina polylepis*
Micro alga	*Coscinodiscus concinnus*
Micro alga	*Coscinodiscus* sp.
Micro alga	*Fibrocapsa japonica*
Micro alga	*Gyrodinium aureolum*
Micro alga	*Phaeocystis* sp.
Micro alga	*Prymnesium parvum*
Oarweed	*Laminaria digitata*
Serrated wrack	*Fucus serratus*
Wrack	*Fucus* sp.
Other organisms	
Bacteria	*Escherichia coli*
Parasitic protozoan	*Labyrinthula macrocystis*

ABBREVIATIONS

μ (prefix)	micro, 10^{-6}
ΣPCB	Sum of concentrations for individual chlorinated biphenyl congeners
Σ (prefix)	Sum (of concentrations)
°C	Degrees Celsius
4NSC	Fourth International Conference on the Protection of the North Sea, Esbjerg Denmark 1995
5NSC	Fifth International Conference on the Protection of the North Sea due to be held in 2002
ACFM	Advisory Committee on Fisheries Management (ICES)
ACG	Assessment Coordination Group (OSPAR)
AHTN	7-acetyl-1,1,3,4,4,6-hexamethyl-1,2,3,4-tetrahydronaphtalene
AMAP	Arctic Monitoring and Assessment Programme
ASCOBANS	Agreement on Small Cetaceans of the Baltic and North Sea
ASMO	Environmental Assessment and Monitoring Committee (OSPAR)
ASP	Amnesic Shellfish Poisoning
atm	1 atmosphere = 1.013 x 10^5 Pascal
BAT	Best Available Techniques
BC	Before Christ
BDE-47	A brominated diphenyl ether
BEP	Best Environmental Practice
BFR	Brominated flame retardant
Bq	Becquerel (1 disintegration per second)
BRC	Background / Reference Concentration
BSH	Bundesamt für Seeschiffahrt und Hydrographie (Germany)
CAMP	Comprehensive Atmospheric Monitoring Programme (OSPAR)
CB	Chlorinated Biphenyl
CEFAS	Centre for Environment, Fisheries and Aquaculture Science (UK)
CHB	Chlorinated bornane (congener)
cm	Centimetre
CPs	Chlorinated paraffins
d	Day
DBT	Dibutyltin
DDD	pp'-dichlorodiphenyldichloroethane
DDE	1,1-dichloro-2-(2-chlorophenyl)-2-(4-chlorophenyl)ethene
DDT	4,4'-dichlorodiphenyl-1,1,1-trichloroethane
DeBDE	Decabromodiphenylether
DIN	Dissolved Inorganic Nitrogen
DON	Dissolved organic nitrogen
dw	Dry weight
EAC	Ecotoxicological Assessment Criteria
EC	European Commission
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
EROD	E–thoxyresorufin-*O*-deethylase
ERSEM	European Regional Seas Ecosystem Model
EU	European Union
fw	fat weight
G (prefix)	Giga, 10^9
GDR	German Democratic Republic
GOOS	Global Ocean Observation System
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
HHCB	1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta-(g)-2-benzopyrane
ICES	International Council for the Exploration of the Sea
ICRP	International Commission on Radiological Protection
IMM 1997	Intermediate Ministerial Meeting on the Integration of Fisheries and Environmental Issues (5NSC)
IMO	International Maritime Organization
IMPACT	Working Group on Impacts on the Marine Environment (OSPAR)
IMR	Institute for Marine Research (Norway)
INPUT	Working Group on Inputs to the Marine Environment (OSPAR)
IPCC	UN Intergovernmental Panel on Climate Change
IUPAC	International Union for Pure Applied Chemistry
IWC	International Whaling Commission
JAMP	Joint Assessment and Monitoring Programme (OSPAR)
kg	Kilogramme
km	Kilometre
km^2	square kilometre
km^3	Cubic kilometre
LC_{50}	Lethal concentration at which 50% of the population of test organisms die
Lw	Lipid weight
M	Molar mass
M (prefix)	Mega, 10^6
MAGP	Multi-Annual Guidance Programme (For Fisheries)
MARPOL	International Convention for the Prevention of Pollution from Ships (1973/1978)
MBT	Monobutyltin
MEPC	IMO Marine Environmental Protection Committee
Mm	Millimetre
MMC	Ministerial Meeting of the (OSPAR) Commission
MMHg	Monomethylmercury
MON	Ad Hoc Working Group on Monitoring (OSPAR)
MPA	Marine Protected Area
n (prefix)	nano, 10^{-9}
NAO	North Atlantic Oscillation
NATO	North Atlantic Treaty Organization
NERC	Natural Environment Research Council (UK)
NIVA	Norwegian Institute for Water Research
nm	Nautical mile
NPE	Nonylphenol ethoxylate
NSP	North Sea Project
NSTF	North Sea Task Force
OBMs	Oil-based muds
OPE	Octylphenol ethoxylate
OSPAR Commission	The term 'OSPAR Commission' is used in this report to refer to both the OSPAR Commission and the former Oslo and Paris Commissions. The 1972 Oslo Convention and the 1974 Paris Convention were replaced by the 1992 OSPAR Convention when it entered into force on 25 March 1998
p (in pCO_2)	Partial pressure
p (prefix)	pico, 10^{-12}
PAH	Polycylic Aromatic Hydrocarbon
PARCOM	Paris Commission (now part of the OSPAR Commission)
PBB	Polybromobiphenyls
PBDEs	Polybrominated diphenyl ethers
PCBs	Polychlorinated Biphenyls
PCDD	Polychlorodibenzodioxins
PCDF	Polychlorodibenzofuranes
PCT	Polychlorinated terphenyls
PON	Particulate organic nitrogen
PRAM	Programmes and Measures Committee (OSPAR)
PSP	Paralytic Shellfish Poisoning
PVC	polyvinyl chloride
QSR	Quality Status Report
QSR 2000	Quality Status Report for the entire OSPAR maritime area published by OSPAR in 2000
RID	Comprehensive Study on Riverine Inputs and Direct Discharges (OSPAR)
RTT	Regional Task Team (OSPAR)
s	Second (time)
SIME	Working Group on Concentrations, Trends and Effects of Substances in the Marine Environment (OSPAR)
SOC	Southampton Oceanography Centre
SPM	Suspended Particulate Matter
Sv	Sievert (1 J kg^{-1} x (modifying factors))
t	Tonne
T (prefix)	Tera, 10^{12}
TAC	Total Allowable Catch
TBT	Tributyltin
TEQ	Toxic equivalent
UN	United Nations
UNCED	UN Conference on Environment and Development
UNEP	United Nations Environment Programme
W	Watt
ww	Wet weight
yr	Year

GLOSSARY

Advection	The transfer of heat or matter by horizontal movement of water masses
Anoxia	A complete absence of oxygen
Anthropogenic	Caused or produced by human activities
ASP biotoxins	The toxin domoic acid (and isomers) produced by certain species of diatoms that, if transmitted through the food web, causes a syndrome known as Amnesic Shellfish Poisoning (ASP) because it is mainly caused after the ingestion of shellfish with amnesia being the main symptom
Background concentrations of natural compounds	The concentration of a natural compound that would be found in the environment in the absence of human activity. Natural compounds are those produced by biosynthesis from natural precursors or by geochemical, photochemical or chemical processes.
Background/Reference Concentrations (BRCs)	The following operational definitions have been used by OSPAR to determine Background/ Reference Concentrations (BRCs): concentrations reflecting geological times (obtained from layers of buried marine sediments) or concentrations reflecting historical times (obtained from measurements carried out prior to significant anthropogenic inputs of the respective substance; relevant for nutrients only) or concentrations from pristine areas (preferably areas far from known sources and normally having very low concentrations)
Benthos	Those organisms attached to, living on, or in the seabed. Benthos is categorised by its diameter into: - nanobenthos: passes through 63 µm mesh - microbenthos: passes through 100 µm mesh - meiobenthos: within the 100 – 500 µm range - macrobenthos: passes through 1 cm mesh but is retained on 1000 – 500 µm mesh - megabenthos: visible, sampled using trawls and sieves
Bioaccumulation	The accumulation of a substance within the tissues of an organism. This includes 'bioconcentration' and uptake via the food chain.
Bioassay	The use of an organism for assay purposes. Generally referring to a technique by which the presence of a chemical is quantified using living organisms, rather than chemical analyses
Bioavailability	The extent to which a substance can be absorbed into the tissues of organisms. Possibly the most important factor determining the extent to which a contaminant will enter the food chain and accumulate in biological tissues
Bioconcentration	The net result of the uptake, distribution and elimination of a substance by an organism due to water-borne exposure
Biomagnification	The process whereby concentrations of certain substances increase with each step in the food chain
Biomass	The total mass of organisms in a given place at a given time
Biota	Living organisms
Bloom	An abundant growth of phytoplankton, typically triggered by sudden favourable environmental conditions (e.g. excess nutrients, light availability, reduced grazing pressure)
By-catch	Non-target organisms caught in fishing gear
Climate	The long-term average conditions of the atmosphere and/or ocean
Contaminant	Any substance detected in a location where it is not normally found
Continental margin	The ocean floor between the shoreline and the abyssal plain, including the continental shelf, the continental slope and the continental rise
Continental shelf	The shallowest part of the continental margin between the shoreline and the continental slope; not usually deeper than 200 m
Continental slope	The steeply sloping seabed from the outer edge of the continental shelf to the continental rise
Contour current	An ocean current flowing approximately parallel to the bathymetric contours on the ocean bottom
Diagenesis	The chemical and physical processes, in particular compaction and cementation, involved in rock formation after the initial deposition of a sediment
Diel vertical migration	Daily (24 hour) migrations undertaken by pelagic animals that generally move up towards the surface at dusk and then return to deeper water at dawn
Discards	Fish and other organisms caught by fishing gear and then thrown back into the sea
Dissolved Organic Carbon (DOC)	Carbon in organic compounds that are in solution in sea water
Diversity	The genetic, taxonomic and ecosystem variety in organisms in a given marine area
DSP biotoxins	A group of toxins produced by some marine dinoflagellates that, if transmitted through the food web, cause a syndrome known as Diarrhetic Shellfish Poisoning (DSP) because it is mainly caused after the ingestion of shellfish and with diarrhoea being the main symptom
Dumping	The deliberate disposal in the maritime area of wastes or other matter from vessels or aircraft, from offshore installations, and any deliberate disposal in the maritime area of vessels or aircraft, offshore installations and offshore pipelines. The term does not include disposal in accordance with MARPOL 73/78 or other applicable international law of wastes or matter incidental to, or derived from, the normal operations of vessels or aircraft or offshore installations (other than wastes or other matter transported by or to vessels of offshore installations for the purpose of disposal of such wastes or other matter or derived from the treatment of such wastes or other matter on such vessels or aircraft of offshore installations)
Ecotoxicological assessment criteria (EAC)	The concentrations that, according to existing scientific knowledge, approximate to concentrations below which the potential for adverse effects is minimal
Ecosystem	A community of organisms and their physical environment interacting as an ecological unit
Ecosystem approach	The ecosystem approach (to fisheries management) involves a consideration of all the physical, chemical and biological variables within an ecosystem, taking account of their complex interactions. In the management of living resources this means that the decisions are based upon the best available scientific knowledge of the functions of the ecosystem, including the interdependence of species and the interaction between species (food chains) and the abiotic environment of the ecosystem. It could therefore imply a widening of the multi-species approach, currently used in fisheries, to encompass not only fish but also other organisms which directly or indirectly depend on fish or on which fish depend, as well as other significant biotic and abiotic environmental factors
Emission	A release into air
Endemic	Native, and restricted, to a particular locality or specialised habitat
Endocrine disrupter	An exogenous substance that causes adverse health effects in an intact organism, or its progeny, consequent to changes in endocrine function. In applying this definition to the marine environment it will be necessary to consider substances that are likely directly or indirectly to affect the hormonal regulation in whole organisms by the mimicking of hormones or by affecting enzyme systems responsible for hormone equilibria.
Euphotic zone	The upper layers of the sea with sufficient light penetration for net photosynthesis to occur
Eutrophication	The enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients
Exclusive Economic Zone (EEZ)	An area in which a coastal state has sovereign rights over all the economic resources of the sea, seabed and subsoil (see Articles 56 – 58, Part V, UNCLOS 1982)
Fisheries management	In adopting Annex V to the 1992 OSPAR Convention, on the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area, OSPAR agreed that references to 'questions relating to the management of fisheries' are references to the questions on which action can be taken under such instruments as those constituting: - the Common Fisheries Policy of the European Community; - the corresponding legislation of Contracting Parties which are not Member States of the European Union; - the corresponding legislation in force in the Faroe Islands, Greenland, the Channel Islands and the Isle of Man; or - the North East Atlantic Fisheries Commission and the North Atlantic Salmon Commission; whether or not such action has been taken. For the avoidance of doubt, in the context of the OSPAR Convention, the management of fisheries includes the management of marine mammals
Focus areas	An area of special attention in the QSRs. They may consist of a typical and valuable habitat for marine life, may be under (anthropogenic) stress, may be of strategic or economic importance, or scientific research may have resulted in a relatively large amount of information on the area
Food web	The network of interconnected food chains along which organic matter flows within an ecosystem or community
Fossil fuel	Mineral fuels (coal and hydrocarbons) rich in fossilised organic materials which are burnt to provide energy
Fronts	The boundary zone between two water masses differing in properties, such as temperature and salinity. Fronts can be either convergent or divergent
Geochemical	Relating to the natural chemistry of the Earth
Glacial periods	Cool to cold climatic periods, characterised by advancing ice sheets and caps, within the Quaternary Period

Gyre	Large-scale ocean circulation pattern generated by the interaction of winds and the rotation of the earth
Harmful Algal Blooms (HAB)	Blooms of phytoplankton that result in harmful effects such as the production of toxins that can affect human health, oxygen depletion and kills of fish and invertebrates and harm to fish and invertebrates e.g. by damaging or clogging gills
Hazardous substances	Substances which fall into one of the following categories: (i) substances or groups of substances that are toxic, persistent and liable to bioaccumulate; or (ii) other substances or groups of substances which are assessed by OSPAR as requiring a similar approach as substances referred to in (i), even if they do not meet all the criteria for toxicity, persistence and bioaccumulation, but which give rise to an equivalent level of concern
Hepatopancreas	The combined stomach and pancreatic glands typical of crustaceans
Hydrography	The study of water characteristics and movements
Imposex	A condition in which the gender of an organism has become indeterminate as a result of hormonal imbalances or disruption, as in the case of the effect of tributyltin on gastropods
Inshore waters	Shallow waters on the continental shelf, a term usually applied to territorial waters within 6 miles of the coasts
Interglacial periods	Warm to temperate periods between glaciations within the Quaternary Period
Internal waves	Waves occurring on density surfaces within the ocean and most commonly generated by the interaction between tidal currents and the sea bed structure
Intrusion	Water that is intermediate in density between two contiguous water masses and so flows between them
Isotope	A form of an element chemically identical to another but with a different atomic weight
Key species	A species whose loss would have a detrimental or disproportionate effect on the structure, function and/or biological diversity of the ecosystem to which it belongs
London Convention	The 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter. The Convention is administered by the International Maritime Organization
MARPOL 73/78	The International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto
Mesoscale eddy	An eddy with dimensions of 10 – 200 km
Meteorology	The study of weather and climate
Microbial food web	The food web that is sustained by picoplankton cells that are too small to be filtered from the water by suspension feeders
Multi-species approach	A form of management that takes into account interaction between the different components in the food webs of the ecosystems
North Atlantic Oscillation (NAO)	The North Atlantic Oscillation index is defined as the difference in atmospheric pressure at sea level between the Azores and Iceland and describes the strength and position of westerly air flows across the North Atlantic
Nutrients	Dissolved phosphorus, nitrogen and silica compounds
Organohalogens	Substances in which an organic molecule is combined with one or more of the halogen group of elements (i.e. fluorine, chlorine, bromine, iodine)
Pelagic deposits	Deep ocean sediments containing no significant terrigenous component and derived mainly from the sinking of lithogenic and biological particles formed in the oceanic water column
Phytoplankton	The collective term for the photosynthetic members of the nano- and microplankton
Plankton	Those organisms that are unable to maintain their position or distribution independent of the movement of the water. Plankton is categorised by its diameter into: - picoplankton: < 2 µm - nanoplankton: 2 – 20 µm - microplankton: 20 – 200 µm - macroplankton: 200 – 2000 µm - megaplankton: > 2000 µm
Pollutant	A substance (or energy) causing pollution
Pollution	The introduction by man, directly or indirectly, of substances or energy into the maritime area which results, or is likely to result, in hazards to human health, harm to living resources and marine ecosystems, damage to amenities or interference with other legitimate uses of the sea
Post-spawning	Pertaining to a population of organisms following breeding
Production, primary	The assimilation of organic matter by autotrophs (i.e. organisms capable of synthesising complex organic substances from simple inorganic substrates; including both chemoautotrophic and photoautotrphic organisms). Gross production refers to the total amount of organic matter fixed in photosynthesis and chemosynthesis by autotrophic organisms, including that lost in respiration. Net production is that part of assimilated energy converted into biomass and reflects the total amount of organic matter fixed by autotrophic organisms less that lost in respiration
Production, secondary	The assimilation of organic matter by heterotrophic organisms (organisms unable to synthesise organic compounds from inorganic substrates)
Radionuclide	Atoms that disintegrate by emission of electromagnetic radiation, i.e. emit alpha, beta or gamma radiation
Recruitment (fisheries)	The process by which young fish enter a fishery, either by becoming large enough to be retained by the gear in use or by migrating from protected areas into areas where fishing occurs
Remineralisation	The conversion of a substance from an organically bound form back to a water-soluble inorganic form, resulting in the release of inorganic nutrients (e.g. nitrate, phosphate), carbon dioxide or methane back into solution
Safe biological limits	Limits (reference points) for fishing mortality rates and spawning stock biomass, beyond which the fishery is unsustainable. Other criteria which indicate when a stock is outside safe biological limits include age structure and distribution of the stock and exploitation rates. A fishery which maintains stock size within a precautionary range (a range within which the probability of reaching any limits is very small) would be expected to be sustainable
Salinity	A measure of the total amount of dissolved salts in sea water
Slope current	A current that follows the shelf break along a continental margin
Standing crop	The biomass of organisms per unit volume at a given time
Subduction	The process by which crustal material is returned to the upper mantle and occurs where dense oceanic crust slips beneath less dense continental crust
Sverdrup	A unit of transport used in oceanography to quantify flow in ocean currents. It is equivalent to 10^6 m^3/s
Thermocline	A boundary region in the sea between two layers of water of different temperature, in which temperature changes sharply with depth
Topography	The land forms or surface features of a geographical area
Total allowable catch (TAC)	The maximum tonnage, set each year, that may be taken of a fish species within an area. In the EU, the TAC is a central part of the Common Fisheries Policy. It establishes the total amount of each species that may be caught in EU waters annually. Each year the Council of Ministers establishes TACs for each species, and then each Member State is allocated a quota for each species
Toxaphene	A chlorinated insecticide with an average chemical composition of $C_{10}H_{10}C_{18}$. Primarily used in cotton farming
Toxin	A biogenic (produced by the action of living organisms) poison, usually proteinaceous
Trace organic compounds	A compound containing carbon as an essential component and present in the environment in minute quantities only. There are no known natural sources of some organochlorine compounds (such as PCBs, DDT and herbicides), while others (such as some PAHs) do have natural sources
Trench	A narrow, elongated U-shaped depression of the deep ocean floor between an abyssal plain and the continental margin where subduction of oceanic crust occurs
Trophic	Pertaining to nutrition
Upwelling	An upward movement of cold, nutrient-rich water from ocean depths; this occurs near coasts where winds persistently drive water seawards and in the open ocean where surface currents are divergent
Vas deferens	The sperm duct
Vitellogenin	A protein in blood plasma used as a biomarker for exposure to endocrine disrupters that promote the development of female sex characteristics
Water column	The vertical column of water extending from the sea surface to the seabed
Water mass	A body of water within an ocean characterised by its physicochemical properties of temperature, salinity, depth and movement
Zooplankton	The animal component of the plankton; animals suspended or drifting in the water column including larvae of many fish and benthic invertebrates

REFERENCES

Chapter 1 References

North Sea Task Force 1993. North Sea Quality Status Report 1993. Oslo and Paris Commissions, London; Olsen and Olsen, Fredensborg, Denmark. 132 pp.

Chapter 2 References

Aure, J., Danielssen, D. and Sætre, R. 1996. Assessment of eutrophication in Skagerrak coastal waters using oxygen consumption in fjordic basins. *ICES J. Mar. Sci.* 53: 589–595.

Backhaus, J.O. 1984. Estimates of the variability of low frequency currents and flushing times of the North Sea. ICES Hydrography Committee, Copenhagen, C.M. 1984/C: 24.

Bacon, S. and Carter, D.J.T. 1991. Wave climate changes in the North Atlantic and North Sea. *Int. J. Climat.* 11: 545–558.

Bacon, S. and Carter, D.J.T. 1993. A connection between mean wave height and atmospheric pressure gradient in the North Atlantic. *J. Climat.* 13: 423–436.

Barrett, E.C., Beaumont, M.J. and Corlyon, A. M. 1991. Satellite-derived rainfall atlas of the North Sea 1978–87. University of Bristol, 164 pp.

Becker, G.A. 1990. Die Nordsee als physikalisches System. In *Warnsignale aus der Nordseewissenschaftliche Fakten.* J.L. Lozan, W. Lenz, E. Rachor, B. Watermann and Westerhagen H. (Eds.). Paul Parey, Berlin and Hamburg. 428 pp.

Becker, G.A., Frohse, A. and Damm, P. 1997. The Northwest European Shelf temperature and salinity variability. *Dt. Hydrogr*. Z. 49: 145–161.

Becker, G. and Schulz, A. 2000. Atlas of the North Sea surface temperature. *Dt. Hydr. Z*. (Supl.), in press.

Boon, J., van der Kaaij, T., Vos, R.J. and Gerritsen, H. 1997. Modelling of suspended particulate matter (SPM) in the North Sea; Model set-up and first sensitivity analysis. Delft Hydraulics report Z2025.

Breton, M., Salomon, J.C. and Guéguéniat, P. 1992. Sixth international biennial conference on physics of estuaries and coastal areas. Margaret River, Western Australia.

Dickson, R.R., Meincke, J., Malmberg, S.-A. and Lee, A. 1988. The 'Great Salinity Anomaly' in the northern North Atlantic 1968– 1982. *Prog. Oceanogr*. 20: 103–151.

Dooley, H.D. and Furnes, G.K. 1981. Influence of the wind field on the transport of the northern North Sea. In: The Norwegian coastal current; R. Sætre and M. Mork (Eds.). University of Bergen Vol. 1, pp. 57–71.

Dupont, J.-P., Lafite, R. and Eisma, D. 1991. Comparaison de la dynamique du matériel en suspension dans les eaux côtières de la Manche orientale et de la baie méridionale de la mer du Nord. In: Estuaries and coasts: Spatial and temporal intercomparisons; M. Elliott and Ducrotoy, J.P. (Eds.). Olsen and Olsen, Fredensborg, Denmark, pp. 57–62.

Eisma, D., 1981. Supply and deposition of suspended matter in the North Sea. Spec. Publs int. Ass. Sedimentol. 5: 415–428, Blackwell, Oxford.

Eisma, D. and Irion, G. 1988. Suspended matter and sediment transport. *In: Pollution of the North Sea: An assessment;* W. Salomons et al. (Eds). Springer, Berlin, pp. 20–33.

Ellet, D.J., and Turrell, W.R. 1992. Increased salinity levels in the NE Atlantic. ICES 1992/C: 20.

Flather, R. 1987. Estimates of extreme conditions of tide and surge using a numerical model of the north-west continental shelf. *Estuar. coastal Shelf Sci.*, 24: 69–93.

Furnes, G.K. and Saelen, O.H. 1977. Current and hydrography in the Norwegian Coastal Current off Utsira during JONSDAP 76. Norwegian Coastal Project, Rep. 2/77, University of Bergen, Norway.

Furnes, G.K., Hackett, B. and Sætre, R. 1986. Retroflexion of Atlantic water in the Norwegian Trench. *Deep Sea Res*. 33: 247–265.

Furnes, G.K. 1992. Climatic variations of oceanographic processes in the north European seas: A review of the 1970s and 1980s. *Cont. Shelf Res.* 12: 235–256.

Hardisty, J. 1990. The British Seas, an introduction to the new oceanography and resources of the north-west European continental shelf. Routledge, London. 272 pp.

Heath, M.R., Henderson, E.W., Slesser, C., and Woodward, E.M.S. 1991. High salinity in the North Sea. *Nature*, 352: 116.

HELCOM, 1996. Third Periodic Assessment of the State of the Marine Environment of the Baltic Sea, 1989–93. Background document. Balt. Sea Environ. Proc. No. 64 B.

Hurrel, J. 1995. Decadal trends in the North Atlantic Oscillation regional temperatures and precipitation. *Science*, 269: 676–679.

ICES. 1983. Flushing times of the North Sea. Coop. Res. Rep. Cons. int. Explor. Mer, No. 123. 159 pp.

IPCC (Intergovernmental Panel on Climate Change), 1996. Climate Change 1995. The Science of Climate Change. Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N. Kattenberg, A., Maskell, K. (Eds.) Cambridge University Press, Cambridge, 572 pp.

Iversen S.A., Skogen, M.D., Svendsen, E. 1998. Influx of Atlantic Water and Feeding Migration of Horse Mackerel. ICES C.M. 1998/R:18. pp. 9.

Johannessen, J.A., Svendsen, E., Sandven, S., Johannessen, O.M. and Lygre, K. 1989. Three-dimensional structure of mesoscale eddies in the Norwegian coastal current. *J. phys. Oceanogr.*, 19: 3–19.

Lenhart, H.J.and Pohlmann, T. 1997. The ICES-boxes approach in relation to results of a North Sea circulation model. *Tellus*, 49A, 139–160.

Ljøen, R. and Svansson, A. 1972. Long-term variations of sub-surface temperatures in the Skagerrak. *Deep Sea Res.* 19: 277–288.

Ljøen, R. 1981. On the exchange of deep waters in the Skagerrak basin. In: The Norwegian Coastal Current, M. Mork (Ed.) pp. 340–356.

North Sea Task Force 1993. North Sea Quality Status Report 1993. Oslo and Paris Commissions, London. Olsen and Olsen, Fredensborg, Denmark, 132 pp.

Otto, L., Zimmerman, J.T.F., Furnes, G.K., Mork, M., Sætre, R. and Becker, G. 1990. Review of the physical oceanography of the North Sea. *Neth. J. Sea Res.* 26: 161–238.

Philippart, M.E. and Gebraad, A.W. 1997. A new storm surge forecasting system, Operational Oceanography, the challenge for European co-operation. In: Proc. of the First International Conference on EuroGOOS, J.H. Stel *et al.* (Eds.), Elsevier, Amsterdam, pp. 487–495.

Pohlmann, T. and Puls, W. 1994. Currents and transport in water. In: Circulation and contaminant fluxes in the North Sea, J. Sündermann (Ed). Springer, Berlin, pp. 345–402.

Prandle, D. 1978. Residual flows and elevations in the southern North Sea. Proc. R. Soc. Lond. A., 359: 189–228.

Prandle, D. 1984. A modelling study of the mixing of 137Cs in the seas of the European continental shelf. *Phil. Trans. R. Soc.*, London, A310: 407–436.

Prandle, D. 1990. RRS 'Challenger' cruise 66B/90, 3–7 June 1990. Measuring the flux of contaminants through the Strait of Dover. Proudman Oceanogr. Lab. Cruise Report, No. 9, 17 pp.

Prandle, D., Ballard, G., Flatt, D., Harrison, A.J., Jones, S.E., Knight, P.J., Loch, S., McManus, J.P., Player, R. and Tappin, A. 1996. Combining modelling and monitoring to determine fluxes of water, dissolved and particulate metals through the Dover Strait. *Cont. Shelf Res.* 16: 237–257.

Rodhe, J. 1987. The large-scale circulation in the Skagerrak, interpretation of some observations. *Tellus* 39A: 245–253.

Rydberg, L., Haamer, J. and Liungman, O. 1996. Fluxes of water and nutrients within and into the Skagerrak. *J. Sea Res*. 35: 23–38.

Salomon, J.C and Breton, M. 1993a. An Atlas of long term currents in the Channel. Oceanologica Acta, (Channel Symposium: Fluxes and processes with a macrotidal sea). Vol. 16/No. 5-6: 439–448.

Salomon, J.C., Breton, M. Guéguéniat, P. 1993b. Computed residual flow through the Dover Straight. Oceanologica Acta, (Channel Symposium: Fluxes and processes with a macrotidal sea). Vol. 16/No. 5-6: 449–456.

Skogen, M.D., Svensen, E., Berntsen, J., Aksness, D. and Ulvestad, K.B. 1995. Modelling the primary production in the North Sea using a coupled three-dimensional physical-chemical-biological ocean model. Estuar. *Coast. Shelf Sci.* 41: 545–565.

Smith, J.A., Damm, P.E., Skogen, M.D., Flather, R.A. and Pätch, J. 1996. An investigation into transports and the long-term residual circulation of the North-West European Shelf using three hydrodynamic models. *Deut. Hydrogr. Z*. 48: 325–348.

Svendsen, E. and Magnusson, A.K. 1992. Climatic variability in the North Sea. ICES Mar. Sci. Symp., 195: 144–158.

Svendsen, E., Aglen, A., Iversen, S.A., Skagen D.W. and Smestad, O. 1995. Influence of climate on recruitment and migration of fish stocks in the North Sea. In: Climate change and northern fish populations, R.J. Beamish (Ed.). *Can. Spec. Publ. Fish. Aquat. Sci.* 121: 641–653.

Turrell, W.R. 1992. New hypotheses concerning the circulation of the northern North Sea and its relation to North Sea fish stock recruitment. *ICES J. Mar. Sci.* 49: 107–123.

UK Department of Energy 1989. Metocean parameters (wave parameters). Supporting document for offshore installations: guidance on design, construction and certification - environmental considerations. HMSO, OTH 89 300.

Vincent, P. and Le Provost, C. 1988. Semi-diurnal tides in the Northeast Atlantic from a finite element model. *J. Geophys. Res.* 93: 543–555.

von Storch, H. (Ed.) 1996. The WASA project: Changing storm and wave climate in the north-east Atlantic and adjacent seas ? GKSS 96/E/61, 16 pp.

WASA Group 1998. Changing waves and storms in the North-East Atlantic ? Bull. Am. Meteor. Soc. 79: 741–761.

Chapter 3 References

4NSC 1995. Progress Report. 4th International Conference on the Protection of the North Sea. Esbjerg, Denmark, 8-9 June 1995. Andersen J. and Niilonen T. (Eds.). Ministry of the Environment and Energy, Danish Environmental Protection Agency, Copenhagen. 247 pp.

5NSC 1997. Assessment report on Fisheries and Fisheries related Species and Habitat Issues. Svelle M., Aarefjord, H., Heir, H.T. and Øverland, S. (Eds.) Intermediate Ministerial Meeting on the integration of Fisheries and Environmental Issues, 13-14 March 1997, Bergen, Norway. Ministry of Environment, Norway. Fifth North Sea Conference Secretariat. 127 pp.

Britannica 1999. Book of the year - Britannica World Data, 1997. Encyclopaedia Britannica, London. 920 pp.

Cotter J. *et al*. 1999. On-board sampling of fish landed and discarded by commercial vessels. EU Contract ref. EC 95/094. 290 pp.

CWSS 1998. Stade Declaration on Trilateral Wadden Sea Plan 1997. Common Wadden Sea Secretariat, Wilhelmshaven, 100 pp.

De Jong, F., Bakker, J.F., van Berkel, C.J.M., Dankers, N.M.J.A., Dahl, K., Gätje, C., Marencic, H. and Potel, P. 1999. Wadden Sea Quality Status Report. Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven, Germany. 259 pp.

Department of the Environment, Transport and the Regions (UK) 1997. Maritime Statistics. The Stationery Office, London. 63 pp.

Duursma, E.K. (Ed.) 1999. Dumped chemical weapons in the sea – options. Dr. A.H. Heineken Foundation for the Environment, Amsterdam, 60 pp.

EC 1991. Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment. OJ L 135, 30/05/1991 p. 0040–0052.

EC 1992. Council Directive 92/112/EEC of 15 December 1992 on procedures for harmonizing the programmes for the reduction and eventual elimination of pollution caused by waste from the titanium dioxide industry. OJ L 048, 26/02/1993, p. 68.

EC 1998. Regulation EC/850/98 of 30 March 1998 for the Conservation of Fishery Resources through Technical Measures for the Protection of juveniles of marine organisms, OJ L 318, 27/11/1998, p. 63.

European Environment Agency, 1995. Europe's Environment – The Dobris Assessment, D. Stanners and P. Bourdeau (Eds.). European Environment Agency, Copenhagen. 676 pp.

Eurostat 1997a. Decline in births halted in 1996, Principle demographic trends in the EU 1996. Eurostat, Statistics in focus, Population and Social conditions - Theme 3, No. 10. pp. 1–4.

Eurostat 1997b. Beyond the predictable: demographic changes in the EU up to 2050. Eurostat, Statistics in focus, Population and Social conditions - Theme 3, No. 7. pp. 1–8.

Eurostat 1998. Pesticide use in the EU. Eurostat, Statistics in focus, Environment, No. 3, pp. 1–12.

Fischer Weltalmanach 1999. Fischer Taschenbuchverlag. Frankfurt am Main. 665 pp.

Grote Bosatlas 1988. Wolters-Noordhoff, Groningen, The Netherlands.

Hooke, N. 1997. Maritime Casualties 1963 – 1996. Lloyd's Maritime Information Services LLP, London. 741 pp.

ICES 1992. Effects of Extraction of Marine Sediments on Fisheries. ICES Cooperative Research Report, No. 182, 78 pp.

ICES 1994. Report of the Working Group on ecosystem effects of fishing activities. ICES C.M. 1994/Assess/Env:1. 109 pp.

ICES 1997. Report of the Working Group on the effects of extraction of marine sediments on the marine ecosystem. ICES C.M. 1997/E:4. 81 pp.

ICES 1999a. Report of the ICES Advisory Committee on Fishery Management, 1998. Parts 1 and 2. ICES Cooperative Research Report, No. 229. 796 pp.

ICES 1999b. Report of the ICES Advisory Committee on the Marine Environment, 1998. ICES Cooperative Research Report, No 233. 375 pp.

Jacobsen M., Egelund L., Hovdan H., Aabel J.P. 1998. Nedbryting av rørledninger over tid. Olje-og Energidepartementet Report (preliminary report).

Jennings, S., Alvsvag, J., Cotter, A.J., Ehrich, S., Greenstreet, S.P.R., Jarre-Teichmann, A., Mergardt, N., Rijnsdorp, A.D. and Smedstad O. 1999. Fishing effects in Northeast Atlantic shelf seas: patterns in fishing effort, diversity and community structure. III. International fishing effort in the North Sea: an analysis of spatial and temporal trends. *Fish. Res*. 40:125–134.

North Sea Task Force 1993. North Sea Quality Status Report 1993. Oslo and Paris Commissions, London. Olsen and Olsen, Fredensborg, Denmark. 132 pp.

OSPAR 1995. Nutrients in the Convention Area. Oslo and Paris Commissions, London. 60 pp.

OSPAR 1997a. Point and Diffuse Sources. Dumping at Sea in 1994. Oslo and Paris Commissions, London, 76 pp.

OSPAR 1997b. Litter in the coastal and marine environment. OSPAR Commission, meeting document No. IMPACT 97/3/1, 11 pp.

OSPAR 1998a. The extent and impact of fisheries directed at gastropods and bivalves. OSPAR Commission, meeting document No. IMPACT 98/4/1. 17 pp. + 18 annexes.

OSPAR 1998b. Impact of marine sand and gravel extraction. OSPAR Commission, meeting document No. IMPACT 98/14/1, Annex 16, 13 pp.

OSPAR 1999a. Point and diffuse sources. Dumping of Wastes at Sea in 1995 and 1996. OSPAR Commission. London. 104 pp.

OSPAR 1999b. Point and diffuse sources. Part II. Discharges, waste handling and air emissions from offshore installations, 1996-1997. OSPAR Commission. London. 54 pp.

Port of Rotterdam 1999. Port of Rotterdam Statistics 1998. Municipality of Rotterdam. Available: http://www.port.rotterdam.nl/port/GB/statistieken/goederen4.pdf [11 July 2000].

Quell, A. and Klimsa, O. 1997. Gefährdung der marinen Umwelt durch Unfälle im Zusammenhang mit dem Transport seewassergefährdender Güter auf Seeschiffen; eine Risikoanalyse für das deutsche Seegebiet. Dipl.Thesis. Hochschule Bremerhaven. 119 pp.

Rijnsdorp. A.D., Buys, A.M., Storbeck, F. and Visser, E. 1997. The micro-distribution of the Dutch beam trawl fleet fishery between April 1993 and March 1996. RIVO-DLO Report C019/97.

Schöneich, H. (Ed.) 1998. Jahrbuch Bergbau, Erdöl und Erdgas Petrochemie, Elektrizität, Umweltschutz, Verlag Glückauf, Essen, 1200 pp.

UBA 1996. Einflüsse der Fisherei und Aquakultur auf die marine Umwelt. UBA Texte 46-96 Umweltbundesamt, Berlin. 136 pp.

Wirtschaftsbehörde Hamburg 1998. Free and Hanseatic City of Hamburg, State Ministry of economic affairs, Department of ports services and economic infrastructure.

Chapter 4 References

4NSC 1995. Progress Report. 4th International Conference on the Protection of the North Sea. Esbjerg, Denmark, 8-9 June 1995. Andersen J. and Niilonen T. (Eds.). Ministry of the Environment and Energy, Danish Environmental Protection Agency, Copenhagen. 247 pp.

Abrahamsson, K. and Ekdahl, A. 1996. Volatile halogenated compounds and chlorophenols in the Skagerrak. *J. Sea Res*. 35: 73–79.

Baeyens, W. 1998. Evolution of trace metal concentrations in the Scheldt estuary (1978-1995). A comparison with estuarine and ocean levels. *Hydrobiologia*, 366: 157–167.

Baeyens W. and Leermakers M. 1998. Elemental mercury concentrations and formation rates in the Scheldt estuary and the North Sea. *Mar. Chem*. 60: 257–266.

Bailly du Bois, P, P Gueguenat, R Gandon, R Leon and Baron Y. 1993. Percentage contribution of inputs from the Atlantic, Irish Sea, English Channel and Baltic into the North Sea during 1988. *Neth. J. Sea Res*. 31: 1–17.

Bakke, T., Gray, J.S., Lichtentaler, R.G. and Palmork, K.H. 1996. Environmental surveys in the vicinity of petroleum installations on the Norwegian Shelf - 1995. Norwegian Pollution Control Authority, Rapport 97:13. 60 pp (in Norwegian, English summary).

Bakker, J., van de Zande, T. and Smedes, F. 1996. Verontreinigingsgraad van en contaminantgehalte in sediment in de Waddenzee in 1993. Rijksinstituut voor Kust en Zee, The Hague, Report RIKZ-96.027, 49 pp.

Bakker, J.F., Bartelds, W., Becker, P.H., Bester, K., Dijkhuizen, D., Frederiks, B. and Reineking, B. 1999. Marine Chemistry. Chapter 4 in: *Wadden Sea Quality Status Report 1999*. pp. 85–117. De Jong, F. *et al*. Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven, Germany. 259 pp.

Berdowski, J.J.M., Baas, J., Bloos, J.P.J., Visschedijk, A.J.H. and Zandveld, P.Y.J. 1997. The European emission inventory of heavy metals and persistent organic pollutants for 1990. TNO Report UBA-FB, Apeldoorn. 239 pp.

Bester, K., Hühnerfuss, H., Lange, W. and Theobald, N. 1997. Results of non-target screening of lipophilic organic pollutants in the German Bight. I: Benzothiazoles. *Sci. Total Environ*. 207: 111–118.

Bester, K., Biselli, S., Gatermann, R., Hühnerfuss, H., Lange, W., and Theobald, N. 1998. Results of non target screening of lipophilic organic pollutants in the German Bight. III: Identification and quantification of 2,5-dichloroaniline *Chemosphere*, 36: 1973–1983.

Bonn Agreement, 1999. Bonn Agreement Aerial Surveillance Programme - Annual report on aerial surveillance for 1998. Bonn Agreement. London. pp. 11.

Boon, J.P. *et al*. (Eds.) 1997. In vitro biotransformatie van organohalogeen-verbindingen in zeezoogdieren en vogels. Mogelijke gevolgen voor bioaccumulatie en genotoxiciteit. III Gebromeerde vlamvertragers (poly-broomdifenylethers & polybroom bifenylen). Nederlands Instituut voor Onderzoek der Zee, BEON Rapport 97–6.

Boon, J.P., Smith, D.E.C., Lewis, W.E., Klamer, H.J.C., Pastor, D., Westr, P.G., and de Boer, J. 1998. In vitro biotransformatie van organohalogeen-verbindingen in zeezoogdieren en vogels. Mogelijke gevolgen voor bioaccumulatie en genotoxiciteit. IV. Polychloor terfenylen (PCT's). BEON Rapport 98–1. 38 pp.

Camplin, W.C., 1992. Radioactivity in surface and coastal waters of the British Isles, 1990. Aquatic Environment Monitoring Report (29). MAFF, Directorate of Fisheries Research, Lowestoft, UK. 68pp.

Capone, D.G., and Carpenter, E.J. 1982. Nitrogen fixation in the marine environment. *Science*, 217: 1140–1142.

Christensen, P.B.(Ed.), Møhlenberg, F., Lund-Hansen, L.C., Borum, J., Christiansen, C., Larsen, S.E., Hansen, M.E., Andersen, J., and Kirkegaard, J. 1998. The Danish Marine Environment: Has action improved its state? Marine research programme HAV90. Nr.62, pp.120. (Translated from Danish by D.I. Barry).

Daan, R. and Mulder, M. 1996. Long term effects of OBM cutting discharges at 12 locations on the Dutch Continental Shelf. Netherlands Institute for Sea Research, NIOZ Report 1996-6.

Dahlgaard, H., 1995. Transfer of European coastal pollution to the Arctic: Radioactive tracers. *Mar. Pollut. Bull.* 31: 3–7.

Evers, E.H.G., Dulfer, J.W., Schobben, H.P.M., van Hattum, B., Scholten, M.C.Th., Frintrop, P.C.M., van Steenwijk, J.M. and van der Heijdt, L.M. 1997. Oil and oil constituents. An analysis of problems associated with oil in the aquatic environment. National Institute for Coastal and Marine Management, RIKZ Report 97.032, The Hague, pp. 148.

Goerke, H. and Weber, K. 1998. The bioaccumulation of organochlorine residues in *Lania conchilega* (Polychaeta) and its geographical variation between the English Channel and the German Bight. *Chemosphere*, 37: 1283–1298.

ICES, 1997. Toxaphene in the marine environment. In: Report of the ICES Advisory Committee on the Marine Environment, ICES Copenhagen. Annex 5, pp. 141–149.

International Commission on Radiological Protection, 1991. 1990 Recommendations of the International Commission on Radiological Protection. Annual Report. ICRP 21(1-3). Pergamon Press, Oxford, 201 pp.

Kerry, J., Hiney, M., Coyne, R., NicGabhainn, S., Gilroy, D., Cazabon, D. and Smith, P. 1995. Fish feed as a source of oxytetracycline resistant bacteria in the sediments under fish farms. *Aquaculture,* 131: 101–103.

Kerry, J., Coyne, R., Gilroy, D. and Smith, P. 1996. Spatial distribution of oxytetracycline and elevated frequencies of oxytetracycline resistance in sediments beneath a marine salmon farm following oxytetracycline therapy. *Aquaculture,* 145: 31–39.

Kershaw, P. J., D. C. Denoon and Woodhead, D. S. 1999. Observations on the redistribution of plutonium, americium and curium in Irish Sea sediments, 1978-1995: Concentrations and inventories. *J. Environ. Radioact*. 44: 191–221.

Köster, H.W., Marwitz, P.A., Berger, G.W., van Weers, A.W., Hagel, P. and Nieuwenhuize, J. 1990. Oriënterend onderzoek naar polonium-210 en andere natuurlijke radionucliden in Nederlandse aquatische ecosystemen. RIVM, Bilthoven.

Laane, R.W.P.M. (Ed.), 1992. Background concentrations of natural compounds in rivers, sea water, atmosphere and mussels. Report DGGW – 92.033.

Laane, R.W.P.M., G. Groeneveld, A. De Vries, A.J. Van Bennekom and Sydow, J.S. 1993. Nutrients (P, N, Si) in the Channel and the Strait of Dover: Seasonal and year to year variation, and fluxes to the North Sea. In: Transport of carbon and nutrients in lakes and estuaries, Kempe, S., E.T. Degens, and D. Eisma (Eds.), Hamburg. SCOPE/UNEP, 74 (part 6), pp. 275–294.

Laane, R.W.P.M, Southward, A.J., Slinn, D.J., Allen, J., Groeneveld, G. and de Vries, A. 1996a. Changes and causes of variability in salinity and dissolved inorganic phosphate in the Irish Sea, English Channel, and Dutch coastal zone. ICES J*. Mar. Sci.* 53: 933–944.

Laane, R.W.P.M., Svendsen, E., Radach, G., Groeneveld, G., Damm, P., Pätsch, J., Danielssen, D. S., Føyn, L., Skogen, M., Ostrowski, M. and Kramer, K.J.M. 1996b. Variability in fluxes of nutrients (N, P, Si) into the North Sea from Atlantic Ocean and Skagerrak caused by variability in water flow. *Deut. Hydrogr. Z*. 48: 401–419.

Laane, R.W.P.M., Sonneveldt, H., van der Weyden, A., Loch, J. and Groeneveld, G. 1998. Trends in the spatial and temporal distribution of metals (Cd, Cu, Zn and Pb) and organic compounds (PCBs and PAHs) in the Dutch coastal zone sediments from 1981-1996; possible sources and causes for Cd and PCBs. *J. Sea. Res.* 41: 1–17.

Lipshultz, F. and Owens, N.J.P. 1996. An assessment of nitrogen fixation as a source of nitrogen to the North Atlantic Ocean. Biogeochemistry, Howarth, R.W. (Ed.), Vol. 35, 261–274.

Lohse L. *et al*. 1993. Nitrogen cycling in North Sea sediments: interaction of denitrification and nitrification in offshore and coastal areas. Publication 56 of the project Applied Research, the Netherlands Institute for Sea Research (BEWON).

Longva, O. and Thorsnes, T. (Eds.) 1997. Skagerrak in the past and at the present – an integrated study of geology, chemistry, hydrography and micro-fossil ecology. Geological Survey of Norway, Special Publication 8, 100 pp.

Magnusson, K., Ekelund, R., Dave, G., Granmo, Å, Förlin, L., Wennberg, L., Samuelsson, M.-O., Berggren, M., and Brorström-Lundén, E. 1996. Contamination and correlation with toxicity of sediment samples from the Skagerrak and Kattegat. *J. Sea Res*., 35: 223–234.

NIVA 1995. Summary report on levels of polychlorinated dibenzofurans/dibenzo-p-dioxins and non-ortho polychlorinated biphenyls in marine organisms and sediments in Norway. Report No. TA-1242/1995. pp. 19.

Nixon, S.W., Ammermann, J.W., Atkinson, L.P., Berounsky, V.M., Billen, G., Boicourt, W.C., Boynton, W.R., Church, T.M., Ditoro, D.M., Elmgren, R., Gaeber, J.H., Giblin, A.E., Jahnke, R.A., Owens, N.J.P., Pilson, M.E.Q. and Seitzinger, S.P. 1996. The fate of nitrogen and phosphorus at the land-sea margin of the North Atlantic Ocean. *Biogeochemistry,* 35: 141–180.

North Sea Task Force 1993. North Sea Quality Status Report 1993. Oslo and Paris Commissions, London. Olsen and Olsen, Fredensborg, Denmark. 132 pp.

OSPAR 1996. Report of the third OSPAR workshop on ecotoxicological assessment criteria. The Hague, 25-29 November 1996. 34 pp. + 30 annexes.

OSPAR 1997a. Report of the results of the one-off DIFFCHEM survey. OSPAR Commission, meeting document No ASMO 97/4/13 31 pp.

OSPAR 1997b. Agreed Background/Reference Concentrations for Contaminants in Sea Water, Biota and Sediment. Agreed Ecotoxicological Assessment Criteria for Trace Metals, PCBs, PAHs, TBT and some Organochlorine Pesticides. OSPAR Commission, meeting document No. OSPAR 97/15/1, Annexes 5 and 6.

OSPAR 1997c. Report of the Working Group on Concentrations, Trends and Effects of Substances in the Marine Environment, OSPAR Commission, meeting document No. SIME(2) 97/12/1.

OSPAR 1997d. Comprehensive Atmospheric Monitoring Programme (CAMP) Data report on the results of measurements made at coastal stations in 1995. Oslo and Paris Commissions.

OSPAR 1997e. Data Report on the Comprehensive Study on Riverine Input and Direct Discharges (RID) in 1995. Oslo and Paris Commissions.

OSPAR 1997f. Dumping at Sea in 1994. Oslo and Paris Commissions, 75 pp.

OSPAR 1997g. Report on discharges, waste handling and air emissions from offshore installations for 1984-1995. Oslo and Paris Commissions. pp 45–66.

OSPAR 1997h. Report on Discharges of Radioactive Substances by Non-Nuclear Industries. Oslo and Paris Commission. 59 pp.

OSPAR 1997i. Responses to Questionnaire on monitoring being carried out on TBT. OSPAR Commission, meeting documents Nos. SIME(2) 97/3/13 and SIME(2) 97/3/13-Add.1.

OSPAR 1997j. OSPAR/ICES Workshop on the overall evaluation and update of background/reference concentrations for nutrients and for contaminants in sea water, biota and sediments. OSPAR Commission, meeting document No. ASMO 97/4/Info.1. 60 pp.

OSPAR 1997k. Background document concerning the identification of anthropogenic sources of PAH emissions as a basis for making decisions on measures. OSPAR Commission, meeting document No. DIFF 97/7/1. 15 pp.

OSPAR 1998a. Data Report on the Comprehensive Study of Riverine Inputs and Direct Discharges (RID) in 1996. OSPAR Commission.

OSPAR, 1998b. Summary Report of the Comprehensive Study on Riverine Inputs and Direct Discharges (RID) in 1990-1995. OSPAR Commission. 9 pp. + tables and annexes.

OSPAR 1998c. Integrated Assessment of Inputs to the OSPAR Convention Area 1990–1996. Outcome of INPUT Special Assessment Workshop, The Hague 26-27 March 1998. OSPAR Commission, meeting document ASMO 98/5/9. 122 pp.

OSPAR 1998d. Report of the ASMO Modelling Workshop on Transport and Fate of Contaminants. 4–7 November 1997, The Hague. OSPAR Commission.

OSPAR 1998e. Report on waste from the titanium dioxide industry, 1979-1994. OSPAR Commission. 35 pp.

OSPAR 1998f. Assessment of PCB fluxes and inventories relevant to the OSPAR Convention Area. OSPAR Commission, meeting document No. INPUT(1) 98/7/1. 34 pp.

OSPAR 1998g. Trace metals and organochlorines in sediments from the Western Scheldt. OSPAR Commission, meeting document No. ASMO 98/4/Info.2. 19 pp.

OSPAR 1998h. National pilot study on inputs of oil and PAHs via rivers. OSPAR Commission, meeting document No. INPUT(1) 98/5/1.

OSPAR 1998i. Estimations of discharged amounts of chemical substances in produced water in the Norwegian sector in 1996. OSPAR Commission, meeting document No. SEBA 98/5/Info.11.

OSPAR 1998j. Report concerning PAHs, Organohalogens and substances other than oil in aqueous discharges from offshore installations in the Dutch sector in 1996. OSPAR Commission, meeting document No. SEBA 98/5/4.

OSPAR 1998k. Report on liquid discharges from nuclear installations in 1996. OSPAR Commission. Report Point and Diffuse Sources pp. 25–44.

OSPAR 1998l. Sources, inputs and temporal trends of radioactive discharges from nuclear installations for the years 1989 to 1995. OSPAR Commission, meeting document No. PRAM 98/6/4.

OSPAR, 1998m. Technetium-99 Contamination in the North Sea and in Norwegian Coastal Areas 1996 and 1997. OSPAR Commission, meeting document No. PRAM 98/6/Info.1.

OSPAR 1999. Discharges from refineries, 1981-1997. Discharges, Waste Handling and Air Emissions from Offshore Installations for 1996-1997. OSPAR Commission. 54 pp.

OSPAR 2000. Report of an assessment of trends in the concentration of certain metals, PAHs and other organic compounds in the tissues of various fish species and blue mussels. OSPAR Commission Ad Hoc working group on monitoring, 1998.

Petersen G., A. Iverfeldt, and Munthe, J. 1995. Atmospheric Hg species over central and northern Europe. Model calculations and comparison with observations from the Nordic air and precipitation network. *Atmosph. Environ.* 29: 47–67.

Poole, A. J., Denoon, D. C. and Woodhead, D. S. 1997. The distribution and inventory of Cs-137 in sub-tidal sediments of the Irish Sea. Radioprotection - Colloques, 32, C2, 263–270.

Preston, M.R., 1997. Sewage and nutrients in the marine environment: Stimulants for good or vectors for harm? *In: Marine chemistry an environmental analytical chemistry approach.* Gianguzza, A., Pelizzetti, E. and Sammartano, S. (Eds.). Kluwer Academic Publ. Dordrecht, pp. 259–273.

Radach, G. and Genkeler, J. 1997. Gridding of the NOWESP data sets, Nr. 27, *Berichte aus dem Zentrum für Meeres- und Klimaforschung* Reihe B: Ozeanographie, Institut für Meereskunde, Hamburg, 375 pp.

Radach, G. and Heyer, K. 1997. A cadmium budget for the German Bight in the North Sea. *Mar. Pollut. Bull*. 34: 375–381.

Radach, G. and Lenhart, H.J. 1995. Nutrient dynamics in the North Sea: fluxes and budgets in the water column derived from ERSEM. *Neth. J. Sea Res*. 33: 301–335.

Raisbeck, G M, F. Yiou, Z.Q. Zhou, L. Kilius and Kershaw, P.J. 1997. Marine discharges of 129-I by the nuclear reprocessing facilities of La Hague and Sellafield. Radioprotection - Colloques, 32, C2, 91–95.

SOAEFD, 1996. Environmental monitoring of the seas around Scotland 1970-1993. HMSO, Edinburgh.

Salomon, J.C., Breton, M., and Guegueniat, P. 1995. A 2D long term advection dispersion model for the Channel and southern North Sea. Part B: Transit time and transfer function for Cap de La Hague. *J. Mar. Syst*. 6: 515–527.

Samuelsen, O.B., Torsvik, V. and Ervik, A. 1992. Long-range changes in oxytetracycline concentration and bacterial resistance towards oxytetracycline in a fish farm sediment after medication. *Sci. Total Environ*., 114: 25–36.

Schallier, R., Lahousse, L. and Jacques, T.G. 1996. Surveillance aérienne: pollutions marines causées par les navires dans la Zone d'Intérêt de la Belgique en Mer du Nord. Rapport d'activité 1991–1995. Unité de Gestion du Modèle Mathematique de la mer de Nord, Bruxelles. 51 pp.

Scholten, M., Kramer, K. and Laane, R. 1998. Distribution of dissolved metals (Cd, Cu, Pb and Zn) in the North Sea: temporal and geographical trends (1980-1989). ICES J. *Mar. Sci*. 55: 825–834.

Seitzinger, S.P. and Giblin, A.E. 1996. Estimating denitrification in North Atlantic continental shelf sediments. *Biogeochemistry*, 35, 235–274.

Theobald, N., Gaul, H. and Ziebarth, U. 1996. Distribution of organic pollutants in the North Sea and adjacent Seas. *Dtsch. Hydrogr. Z*. Suppl., 6: 81–93.

USEIA 1998. Online publication of the United States Energy Information Administration, North Sea Oil Production, November 1998. Available: http://eia.doe.gov/ [November 1998].

van den Hout, K.D. (Ed.) 1993. The impact of atmospheric deposition of non-acidifying pollutants on the quality of European forest soils and the North Sea. Main report of the ESQUAD project. Report by Delft Hydraulics, RIVM, DLO and IMW-TNO; IMW-TNO report nr R93/329, Delft, pp. 143.

Van Pul, W., Nijenhuis, W. and de Leeuw, F. 1998. Deposition of heavy metals to the Convention waters of OSPAR. RIVM Report 722401016.

Vyncke, W., Roose, P., Hillewaert, H., Guns, P., Van Hoeyweghen, P., Baeten, H. and Hoenig, M. 1997. Trace metals and organochlorines in sediments from the Western Scheldt (1990-1995). Fisheries Research Station, Oostende, Report Nr 244.

Wilken R.D. and Wallschlager, D. 1996. The Elbe river: a special example for a European river contaminated heavily with mercury. In: *Global and Regional Mercury Cycles: Sources, fluxes and mass balances*, Baeyens W.F.J., Ebinghaus, R. and Vasiliev, O. (Eds.). Kluwer Academic Publ., Dordrecht, pp. 317–328.

Chapter 5 References

5NSC 1997. Assessment report on Fisheries and Fisheries related Species and Habitat Issues. Svelle M., Aarefjord, H., Heir, H.T. and Øverland, S. (Eds.) Intermediate Ministerial Meeting on the integration of Fisheries and Environmental Issues, 13-14 March 1997, Bergen, Norway. Ministry of Environment, Norway. Fifth North Sea Conference Secretariat. 127 pp.

Allen, Y., Scott, A.P., Matthiessen, P., Haworth, S., Thain, J.E. and Feist, S. 1999. Survey of estrogenic activity in United Kingdom estuarine and coastal waters and its effects on gonadal development of the flounder *Platichthys flesus. Environ. Toxicol. Chem*. 18: 1791–1800.

Allen, Y., Thain, J., Matthiessen, P., Scott, A.P., Haworth, S. and Feist, S.W. 1997. A survey of oestrogenic activity in UK estuaries and its effects on gonadal development of the flounder *Platichthys flesus*. ICES CM 1997/U:0.

AMAP, 1999. Report of the Workshop on Combined Effects of Contaminants in the Marine Environment, Arctic Monitoring and Assessment Program, Copenhagen, 16-17 November 1998. AMAP Report 99:1. AMAP Oslo. 94 pp.

Brouwer, A., Reijnders, P.J.H., and Koeman, J.H. 1989. Polychlorinated biphenyl (PCB)-contaminated fish induces vitamin A and thyroid hormone deficiency in the common seal *(Phoca vitulina)*. *Aquat. Toxicol.*, 15: 99–106.

Cabioch, F., Le Toquin, A., Boindoiresque, C-F., Meinesz, A. and Verlaque, M. 1992. Guide des Algiers des mers d'Europe. Delachaux et Niestle, 231 pp.

Camphuysen, C.J., Ensor, K., Furness, R.W.., Garthe, S., Huppop, O., Leaper, G., Offringa, H. and Tasker, M.L. 1993. Seabirds feeding on discards in winter in the North Sea. Netherlands Institute for Sea Research, Den Burg, Texel. NIOZ-Rapport 1993–8.

Critchley, A.T. 1983. *Sargassum muticum*: A taxonomic history including world-wide and Western Pacific distributions. *J. Mar. Biol. Assoc. U.K*. 63: 617–625.

De Jong, F., Bakker, J.F., van Berkel, C.J.M., Dankers, N.M.J.A., Dahl, K., Gätje, C., Marencic, H. and Potel, P. 1999. Wadden Sea Quality Status Report. Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven, Germany. 259 pp.

De Jonge, V.N., 1994. Wind driven tidal and annual gross transport of mud and microphytobenthos in the Ems estuary, and its importance for the ecosystem. In: Changes in fluxes in estuaries, K.R. Dyer and R.J. Orth (Eds.), Olsen and Olsen, Fredensborg, Denmark, pp 29–40.

De Smet, W.M.A., 1997. Five centuries of sperm whale strandings along the Flemish coast. *Bull. Inst. Roy.. Sci. Nat. Belgique*, Biologie, 67 (Suppl.): 11–14.

Desbrow, C.; Routledge, E.; Brighty, G.C.; Sumpter, J.P.; Waldock, M. 1998. Identification of estrogenic chemicals in STW effluent. 1. Chemical fractionation and in vitro biological screening. *Environ. Sci. Technol.* 32: 1549–1558.

Essink, K. 1993. Ecologische effecten van baggeren en storten van baggerspecie in het Eems-Dollard estuarium. Rijkswaterstaat, Dienst Getijdewateren. Rapport DGW-93.020.

Essink, K. 1997. RIACON. Risk Analysis of Coastal Nourishment Techniques. National Institute for Coastal and Marine Management/RIKZ, Report RIKZ-97.031

European Commission 1994-98. Kvaliteten af Badevand: badesasonen 1993-1997 (In Danish), reports EUR 18166, EUR 15976, EUR 16755, EUR 17629, EUR 18166; EC, Luxembourg.

Foelsvik, N., J.A. Berge, E.-M. Brevik and Walday, M. 1998. Quantification of organotin compounds and determination of imposex in populations of dog whelks *(Nucella lapillus)* from Norway. *Chemosphere*, 38: 681–691.

Forbes, V.E. and Forbes, T.L. 1997. Dietary absorption of sediment-bound fluoranthene by a deposit-feeding gastropod using the ^{14}C:^{51}Cr dual-labelling method. *Environ. Toxicol. Chem*. 16: 1002–1009.

Förlin, L. *et al*. 1996. Effects of contaminants in roundnose grenadier *(Coryphaenoides rupestris)* and Norway lobster *(Nephrops norvegicus)* and contaminant levels in mussels (*Mytilus edulis*) in the Skagerrak and Kattegat compared to the Faeroe Islands. J. Sea Res. 35: 209–222.

GESAMP 1993. Impact of oil and related chemicals on the marine environment. Group of Experts on the Scientific Aspects of Marine Pollution. GESAMP Report. No. 50. International Maritime Organization, London. 180 pp.

Gray, J.S., T. Bakke, H.J. Beck and Nilssen, I. 1999. Managing the environmental effects of the Norwegian oil and gas industry: From conflict to consensus. *Mar. Pollut. Bull.* 38: 525–530.

Greenstreet, S.P.R. and Hall, S.J. 1996. Fishing and the ground-fish assemblage structure in the north-western North Sea: an analysis of long-term and spatial trends. *J. Animal Ecol*. 65: 577–598.

Hagström, Å., Nielsen, T.G., Petersen, J.K., Forbes, T.L. 1996. Havets Usynlige Liv. Tema-rapport, Miljø og Energiministeriet, Danmarks Miljøundersøgelser. (in Danish).

Hammond, P.S., H. Benke, P. Berggren, D.L. Borchers, S.T. Buckland, A. Collet, M.P. Heide-Jørgensen, S. Heimlich-Boran, A.R. Hiby, M.F. Leopold and Øien, N. 1995. Distribution and abundance of the Harbour Porpoise and other small cetaceans in the North Sea and adjacent waters. Life 92-2/UK/027, final report, Sea Mammal Research Unit, National Environment Research Council, Cambridge.

Harries, J.E., Sheahan, D.A., Jobling, S., Matthiessen, P., Neall, P., Routledge, E., Rycroft, R., Sumpter, J.P., Tylor, T. 1997. Survey of Estrogenic activity in UK inland waters. *Environ. Toxicol. Chem*. 16: 534–542.

Hylland, K., Schaanning, M., Skei, J., Berge, J.A., Eriksen, J.Ø., Sköld, M., Gunnarsson, J. 1997. Interactions between eutrophication and contaminants: Partitioning, bioaccumulation and effects on sediment-dwelling organisms. National Environmental Monitoring Programme (Norway), Report 709/97.

Hüppop, O., 1997. Langzeit-Veränderungen der der Brutbestände Helgoländer See- und Küstenvögel. *SEEVÖGEL*, Zeitschrift Verein Jordsand, Hamburg, 18: 38–44.

Hüppop, O., and Garthe, S. 1995. Vögel und Fischerei in der Nordsee. In: Aktuelle Probleme der Meeresumwelt. Vorträge des 8. wissenschaftlichen Symposiums. 3. - 4. Juni 1998 in Hamburg. *Dt. hydrogr. Z.*, Suppl. 2: 109–115.

ICES 1997a. Report of the ICES Advisory Committee on the Marine Environment, 1997. Coop. Res. Rep. 222: 11–21.

ICES 1997b. Report of the Study Group on the Precautionary Approach to Fisheries Management. ICES CM 1997/Assess:7.

ICES 1998a. Report of the Working Group on the Ecosystem Effects of Fishing Activities. International Council for the Exploration of the Seas, Committee Meeting, 1998 / ACFM / ACME:1 Ref E, 263.

ICES 1998b. Report of the Working Group on Introductions and Transfers of Marine Organisms. ICES CM 1998/ACME:4, 73 pp.

ICES 1999a. Report of the ICES Advisory Committee for Fishery Management, 1998. Coop. Res. Rep 229.

ICES 1999b. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak. ICES CM 1999/ACFM:8

ICES 1999c. Report of the ICES Advisory Committee on the Marine Environment, 1998. ICES Coop. Res. Rep. 233, Annex 8, pp. 297-327.

ICES 1999d. Report of the ICES Advisory Committee on the Marine Environment, 1998. ICES Coop. Res. Rep. 233, Section 12 and Annex 9.

Ide, I., Witten, E.P., Fischer, J., Kalbfus, W., Zellner, A., Stroben, E. and Waterman, B. 1997. Accumulation of organotin compounds in the common whelk *Buccinum undatum* and the red whelk *Neptunea antiqua* in association with imposex. *Mar. Ecol. Prog. Ser*., 152: 197–203.

Jak, R.G. and Scholten M.C.T. 1994. Mesocosm-experimenten TNO Den Helder. Indicaties voor het ontstaan van eutrofiëringsverschijnselen. In: *Effecten van verschuivingen van nutrientenconcentraties op biota in de Nederlandse kustwateren*. C.J.M. Philippart *et al.*, Rijksinstituut voor Kust en Zee/RIKZ, BEON Rapport nr. 94-1.

Jak. R.G. and Michielsen B.F. 1996. Algenbegrazing: een nadere analyse van de invloed van toxicanten op het ontstaan van eutrofiëringsproblemen. Rijksinstituut voor Kust en Zee/RIKZ, BEON Rapport nr. 96-4.

Jak, R.G., Ceulemans M., Scholten M.C.T. and van Straalen N.M., 1998. Effects of tributyltin on a coastal North Sea plankton community in enclosures. *Environm. Toxicol. Chem.*, 17: 1840–1847.

Jones, J.J. and Franklin, A., 1998. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1995 and 1996. Sci. Ser., Aquat. Environ. Monit. Rep., CEFAS, Lowestoft, (51), 116 pp.

Knutzen, J. and Hylland, K. 1998. Monitoring of Sandefjords fjorden and inner Mefjorden 1997-1998. Micro-pollutants and effects in fish and shellfish. Norwegian Institute for Water Research (NIVA), NIVA 3934-1998.

Lang, T., Damm, U., Dethlefsen, V. 1995. Changes in the sex ratio of North Sea dab *(Limanda limanda)* in the period 1981–1995 ICES CM 1995/G:25 Ref E.

Law, R and Rowell, C.A. 1993. Cohort-structured populations, selection responses, and exploitation of the North Sea cod. In: *The exploitation of evolving resources*, T.K Stokes, J. M. McGlade and R. Law (Eds.), Lecture notes in Biomathematics 99, Springer, Berlin, pp. 155–173.

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

Lindesjöö, E. *et al*. 1996. Histopathological and immunohistochemical studies in roundnose grenadier *(Coryphaenoides rupestris)* in the Skagerrak, *North Sea. Mar. Environ. Res*. 42: 229–233.

Longva, O. and Thorsnes, T. (Eds.) 1997. Skagerrak in the past and present – an integrated study of geology, chemistry, hydrography and microfossil ecology. Geological Survey of Norway, Special Publication 8, 100 pp.

Mensink, B.P., Everaarts, J.M., Kralt, J. and ten Hallers-Tjabbes, C.C. 1996. Tributyltin exposure in early life stages induces the development of male sexual characteristics in the common whelk, Buccinum undatum. *Mar. Environ. Res.*, 42: 151–154.

Nienhuis, P.H. and A.C. Smaal (Eds.) 1994. The Oosterschelde estuary (The Netherlands): A case-study of a changing ecosystem. *Hydrobiologia* 282/283: 1–597.

North Sea Task Force. 1993. North Sea Quality Status Report 1993. Oslo and Paris Commissions, London. Olsen and Olsen, Fredensborg, Denmark. 132 pp.

OSPAR 1997. Agreed Ecotoxicological Assessment Criteria for Trace Metals, PCBs, PAHs, TBT and some Organochlorine Pesticides. OSPAR Commission, meeting document No. OSPAR 97/15/1, Annex 6.

Rademaker, M., M. Reckermann, U. Tillmann, A. Tillmann-Mayer, F. Volijn, W. Zevenboom, Houpt, P. 1998. *Fibrocapsa japonica* and *Herterosigma akashiwo:* new observations. Harmful Algal News, an IOC Newsletter on toxic algae and algal blooms. 17: 8–10.

Reijnders, P.J. H. and Reineking, B. 1999. Mammals. In: *Wadden Sea Quality Status Report 1999*. De Jong, F. et al. (Eds.). Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven, Germany. pp. 160–164.

Rice, J. and Gislason, H. 1996. Patterns of change in the size spectra of numbers and diversity of the North Sea fish assemblage, as reflected in survey models. ICES J. *Mar. Sci*. 53: 1214–1225.

Richter, R. 1996. Verbreitung des Makrozoobenthos in den sublitoralen Gebieten der östlichen und nördlichen Deutschen Bucht in Vergleich zu früheren Untersuchungen. Dipl. Thesis, Carl von Ossietzky Universität Oldenburg.

Riegman, R., Flameling I.A. and Noordeloos A.A.M. 1998. Size differential uptake of ammonium, nitrate and urea and phytoplankton growth in the North Sea during spring 1994. *Mar. Ecol. Prog. Ser.,* 173: 85–94.

Rijnsdorp, A.D. 1992. Long-term effects of fishing in North Sea plaice. Ph.D Thesis, University of Amsterdam, 220 pp.

Rijnsdorp, A.D., van Leeuwen, P.I., Daan, N. and Heesen, H.J.L. 1996. Changes in abundance of demersal fish species in the North Sea between 1906-1909 and 1990-1995. ICES J. Mar. Sci., 53: 1054–1062.

Rijnsdorp, A.D., Vethaak, A.D. 1997. Changes in reproductive parameters of North Sea plaice and sole between 1960 and 1995. ICES C.M. 1997/U:14.

Rijnsdorp, A.D. Buys A.M., Storbeck F. and Visser E. 1997. The micro distribution of the Dutch beam trawl fleet fisheries between April 1993 and March 1996; RIVO-DLO report C 019/97.

Roee, T.I., Johnson, S. and Nortug, T. submitted. Bioavailability of polycyclic aromatic hydrocarbons in the North Sea. Environ. Toxicol. Chem.

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

Skjoldal, H. R. *et al*. 1997. The Norwegian North Sea Coastal Water: Eutrophication – Status and Trends. Norwegian State Pollution Control Authority.

Skov, H. 1991. Trends in the oil contamination of seabirds in the North Sea. SULA, 5 (special issue): 22–23.

Skov, H., Christensen, K.D., and Durinck, J. 1996. Trends in marine oil pollution in Denmark 1984-1995: An analysis of beached bird surveys, Arbejdsrapport nr. 1996, Ornis Consult A/S.

Smeenk, C. 1997. Strandings of sperm whales *Physeter macrocephalus* in the North Sea: History and patterns. *Bull. Inst. Roy. Sci. Nat. Belgique, Biologie,* 67-suppl.: 15–28.

Ten Hallers-Tjabbes, C.C. 1979. Sexual dimorphism in *Buccinum undatum* (L.) *Malacol*. 18: 13–17.

Ten Hallers-Tjabbes, C.C., Kemp J.F and Boon J.P. 1994. Imposex in whelks *(Buccinum undatum)* from the open North Sea: Relation to shipping traffic intensities. *Mar. Pollut. Bull*., 28: 311–313.

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

USEPA 1991. Sediment toxicity identification evaluation: Phase I (Characterization), Phase II (Identification), and Phase III (Confirmation) Modifications of Effluent Procedures, G.T. Ankley, M.K. Schubauer-Berigan, J.R. Dierkes, and M.T. Lukasewycz (Ed.), EPA-600/6-91/007.

Van Berchum, A.M. and Wattel G. 1997. De Oosterschelde, van estuarium naar zeearm. Bekkenrapportage 1991-1996. Rijksinstituut voor Kust en Zee, Rapport RIKZ-97.034. 96 pp.

Van Dalfsen, J.A. and Essink K. 1997. RIACON Risk Analysis of coastal nourishment techniques in The Netherlands. National evaluation Report. National Institute for Coastal and Marine Management/RIKZ, Report RIKZ-97.022.

Vrieling, E.G., Koeman R.P.T., Nagasaki K., Ishida Y., Peperzak L., Gieskes W.W.C. and Veenhuis M. 1995. *Chattonella* and *Fibrocapsa* (Raphidophyceae): first observation of, potentially harmful, red tide organisms in Dutch coastal waters. 33: 183–191.

Vroon, J., Storm C. and Coosen J. 1997. Westerschelde, stram of struis? Eindrapport van het project OOSTWEST, een studie naar de beïnvloeding van fysische en verwante biologische patronen in een estuarium. Rijksinstituut voor Kust en Zee, Rapport RIKZ-97.023. 106 pp.

Walker, P.A. and Hyslop, J.R.G. 1998. Sensitive skates and resilient rays – spatial and temporal shifts in ray species composition in the Central and North-western North Sea between 1930 and the present day. ICES J. Mar. Sci. 55: 392–402.

Chapter 6 References

5NSC 1997. Assessment report on Fisheries and Fisheries related Species and Habitat Issues. Svelle M., Aarefjord, H., Heir, H.T. and Øverland, S. (Eds.) Intermediate Ministerial Meeting on the integration of Fisheries and Environmental Issues, 13-14 March 1997, Bergen, Norway. Ministry of Environment, Norway. Fifth North Sea Conference Secretariat. 127 pp.

RA, 1998. Prioritisation of human pressures for the Greater North Sea Quality Status Report 1999; An interactive and iterative Multi Criteria Analysis approach. Results and methodology. Resource Analysis, Delft The Netherlands. Report no. RA/98-332, 27 pp.