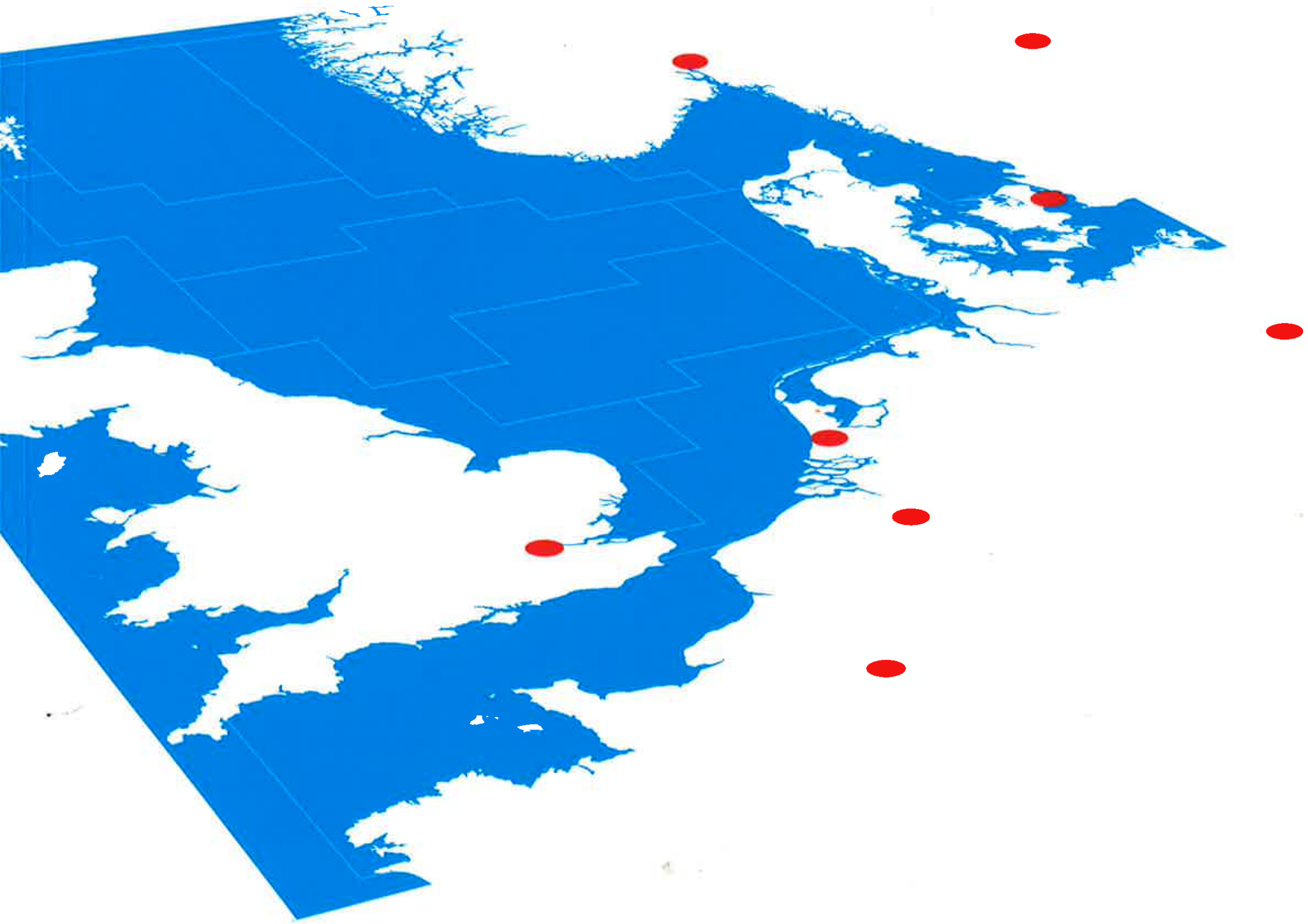
North Sea Quality Status Report 1993

Bilan de santé de la mer du Nord

North Sea Task Force

Oslo and Paris Commissions
International Council for the Exploration of the Sea



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The Foreword, Preface, and Chapter 7
are also presented in French

L'Avant-propos et le Préface ainsi que le Chapitre 7
sont également en français

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North Sea Quality Status Report 1993

Bilan de santé de la mer du Nord

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North Sea Task Force

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Foreword

In 1987, the Ministerial Declaration of the Second International Conference on the Protection of the North Sea identified shortcomings in scientific knowledge of the North Sea environment. Such knowledge was seen as a prerequisite to strategic decisions on environmental protection and to assessments of the effectiveness of measures already taken.

The Ministers considered that the best way to tackle the shortfall in knowledge about the North Sea environment would be to create a task force which would have the following objective:

'To carry out work leading, in a reasonable timescale, to a dependable and comprehensive statement of circulation patterns, inputs and dispersion of contaminants, ecological conditions and effects of human activities in the North Sea.'

The Conference requested the International Council for the Exploration of the Sea (ICES)* and the Oslo and Paris Commissions (OSPARCOM)* to assume joint responsibility for this assignment and to establish a special group to be known as the North Sea Task Force (NSTF). The members of the North Sea Task Force would be the eight North Sea States (Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden, and the United Kingdom) as well as relevant representatives of the Commission of the European Communities, acting under the co-sponsorship of OSPARCOM and ICES. It was agreed that other OSPARCOM States would be able to participate in North Sea Task Force meetings as observers, because similar initiatives in other sea areas were envisaged. The North Sea Task Force commenced its work in late 1988. A central activity was the preparation of a *North Sea Quality Status Report* to be published in 1993 (1993 *QSR*).

The Secretariat of the North Sea Task Force was placed in the Secretariat of the Oslo and Paris Commissions in London, working in close cooperation with the Secretariat of the International Council for the Exploration of the Sea in Copenhagen.

In 1990, the Third International Conference on the Protection of the North Sea invited the North Sea Task Force to address a number of specific topics (i.e., the impact of fishing activities on the ecosystem, surveillance of chemicals not covered in routine monitoring programmes, the environmental impact of persistent chemicals, the role of atmospheric inputs as a source of contaminants, and an assessment of existing damage) in the 1993 *QSR*. It was agreed that the 1993 *QSR* would be discussed at the Intermediate Ministerial Meeting in December 1993. The North Sea Task Force was also invited to carry out a number of additional tasks, such as the elaboration of techniques for developing ecological objectives and the coordination of actions and measures aimed at protecting species and habitats. The results of these activities will be reported to the Fourth International Conference on the Protection of the North Sea in 1995.

* See next page

Avant-propos

En 1987, la Déclaration ministérielle issue de la deuxième Conférence internationale sur la protection de la mer du Nord, définissait les lacunes des connaissances scientifiques sur l'environnement de la mer du Nord. Ces connaissances étaient considérées comme un préalable nécessaire aux décisions stratégiques relatives à la protection de l'environnement ainsi qu'à l'appréciation de l'efficacité des mesures d'ores et déjà prises.

Les ministres ont considéré que la meilleure manière de régler le problème posé par les lacunes des connaissances sur l'environnement de la mer du Nord serait de créer un groupe d'intervention dont l'objectif serait le suivant:

«Entreprendre un travail aboutissant, dans un délai raisonnable, à une déclaration fiable et complète de la structure de circulation, des apports et de la dispersion des polluants, des conditions écologiques et des effets des activités humaines dans la Mer du Nord.»

La conférence a demandé au Conseil International pour l'Exploration de la Mer (CIEM)* ainsi qu'aux Commissions d'Oslo et de Paris (OSPARCOM)* d'assumer en commun la responsabilité de cette mission, et de créer un groupe spécial baptisé Groupe d'intervention mer du Nord (NSTF). Les membres de ce groupe devaient être les huit Etats riverains de la mer du Nord (Allemagne, Belgique, Danemark, France, Norvège, Pays-Bas, Royaume-Uni et Suède), ainsi que les représentants pertinents de la Commission des communautés européennes, agissant sous le parrainage conjoint d'OSPARCOM et du CIEM. Il fut convenu que d'autres Etats membres d'OSPARCOM pourraient participer aux réunions du Groupe d'intervention mer du Nord en qualité d'observateurs, des initiatives analogues étant en effet envisagées dans d'autres zones maritimes. Le Groupe d'intervention mer du Nord a démarré ses travaux à la fin de l'année 1988. L'une de ses missions cruciales était de mettre sur pied un *Bilan de santé de la mer du Nord* devant être publié en 1993 (*QSR* 1993).

Le secrétariat du Groupe d'intervention mer du Nord était installé à Londres, au secrétariat des Commissions d'Oslo et de Paris, et travaillait en étroite collaboration avec le secrétariat du Conseil International pour l'Exploration de la Mer, ce dernier installé à Copenhague.

En 1990, la troisième Conférence internationale sur la protection de la mer du Nord a invité le Groupe d'intervention mer du Nord à aborder, dans le *QSR* 1993, plusieurs thèmes bien précis (à savoir, les conséquences de la pêche pour l'écosystème, la surveillance des produits chimiques non inscrits à des programmes systématiques de contrôle et surveillance, l'impact environnemental des produits chimiques persistants, le rôle des apports atmosphériques à l'origine des polluants, ainsi qu'une appréciation des dommages d'ores et déjà causés). Il fut convenu que le *QSR* 1993 serait débattu en décembre 1993 à la réunion ministérielle intermédiaire. Le Groupe d'intervention mer du Nord fut par ailleurs invité à se livrer à plusieurs missions complémentaires, telles que l'élaboration des techniques de mise au point des objectifs écologiques et la coordination des actions et des mesures visant à protéger les espèces et les habitats. Le résultat de ces activités sera porté à la connaissance de la quatrième Conférence internationale sur la protection de la mer du Nord, qui se tiendra en 1995.

* Voir page suivante

The International Council for the Exploration of the Sea

The International Council for the Exploration of the Sea (ICES) is the oldest intergovernmental organization in the world concerned with marine and fishery science. Since its establishment in 1902, ICES has been a leading scientific forum for the exchange of information and ideas on the sea and its living resources, and for the promotion and coordination of marine research by experts in its eighteen member countries on both sides of the Atlantic. Present member countries of ICES are: Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Latvia, the Netherlands, Norway, Poland, Portugal, Russia, Spain, Sweden, the United Kingdom, and the United States.

The work of ICES is designed to meet the needs not only of its member countries, but also of regulatory commissions concerned with the efficient use of marine fish and shellfish resources in the North Atlantic, including the North Sea and the Baltic Sea, and with the protection of the marine environment from the effects of pollution and other anthropogenic activities.

Under its Convention, the objectives of ICES are 1) to promote and encourage research and investigations for the study of the marine environment and its living resources in the North Atlantic and adjacent seas, and 2) to publish or otherwise disseminate the results of this research, including the provision of scientific information and advice to national governments and regional fishery management and pollution control commissions.

Work organized by ICES is carried out under the Advisory Committee on Fishery Management and the Advisory Committee on the Marine Environment, twelve Subject/Area Committees, and approximately 90 Working, Steering, and Study Groups. The ICES Secretariat operates extensive databases on fisheries, oceanography, and marine contaminants.

The Council's activities are based on the premise that international cooperation in research is vital for the conservation and rational exploitation of aquatic resources and the protection of the marine environment.

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Le Conseil International pour l'Exploration de la Mer

Le Conseil International pour l'Exploration de la Mer (CIEM) est, au monde, la plus ancienne des organisations intergouvernementales qui soient chargées des sciences de la mer et de la pêche. Depuis 1902, date de sa création, le CIEM est une instance scientifique de premier plan où échanger des informations et des idées sur la mer et sur ses ressources vivantes, et où promouvoir et coordonner les recherches sur la mer, auxquelles se livrent des experts émanant de ses dix-huit pays membres des deux côtés de l'Atlantique. Les pays membres actuels du CIEM sont: l'Allemagne, la Belgique, le Canada, le Danemark, l'Espagne, les Etats-Unis, la Finlande, la France, l'Irlande, l'Islande, la Lettonie, la Norvège, les Pays-Bas, la Pologne, le Portugal, la Russie, le Royaume-Uni et la Suède.

Les travaux du CIEM sont conçus pour répondre aux besoins non seulement de ses pays membres, mais également à ceux des commissions régulatrices chargées de l'exploitation rationnelle des ressources marines en poissons, crustacés et mollusques dans l'Atlantique nord, ainsi qu'en mer du Nord et en mer Baltique, et de la protection du milieu marin contre les effets de la pollution et autres activités anthropogènes.

Selon la convention dont il fait l'objet, les objectifs du CIEM sont 1) de promouvoir et d'encourager la recherche sur et l'étude du milieu marin et de ses ressources vivantes dans l'Atlantique nord et dans les mers adjacentes, et 2) de publier ou divulguer de quelconque autre manière les résultats de ces recherches, dont la mise à disposition d'informations scientifiques et la prestation de conseils aux gouvernements nationaux ainsi qu'aux commissions régionales chargées de la gestion des pêcheries et de la lutte contre la pollution.

Les travaux organisés par le CIEM sont réalisés par le Comité d'avis sur la gestion des pêches et par le Comité d'avis sur l'environnement marin, par douze comités thématiques/sectoriels, ainsi que par environ 90 groupes de travail, comités directeurs et groupes d'étude. Le secrétariat du CIEM exploite de vastes banques de données sur les pêcheries, l'océanographie et les polluants des océans.

Dans ses activités, le Conseil part du principe que la coopération internationale dans la recherche est d'une importance cruciale pour la préservation et pour l'exploitation rationnelle des ressources aquatiques, ainsi que pour la protection du milieu marin.

International Council for the Exploration of the Sea

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The Oslo and Paris Commissions

The Oslo and Paris Commissions (OSPARCOM) were established to administer the Oslo and Paris Conventions, which are briefly described below.

The Oslo Convention, or Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, 1972, entered into force in 1974. Its Contracting Parties are: Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom. The purpose of the Convention is to regulate dumping operations involving industrial wastes, dredged material, and sewage sludge in the Convention area. Most of these operations have now been discontinued; industrial wastes will cease to be dumped in 1995 and sewage sludge in 1998. The Commission will continue to regulate the dumping of dredged material through a set of guidelines. The Oslo Convention also regulated incineration at sea until this practice was discontinued in January 1991.

The Paris Convention, or Convention for the Prevention of Marine Pollution from Land-Based Sources, 1974, came into force in 1978. Its Contracting Parties are: Belgium, Denmark, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom. The European Economic Community and Lux-

Les Commissions d'Oslo et de Paris

Les Commissions d'Oslo et de Paris (OSPARCOM) ont été créées afin d'administrer les Conventions d'Oslo et de Paris, brièvement évoquées ci-après.

La Convention d'Oslo, ou Convention de 1972 pour la prévention de la pollution marine par les opérations d'immersion effectuées par les navires et aéronefs, est entrée en vigueur en 1974. Ses Parties contractantes sont: l'Allemagne, la Belgique, le Danemark, l'Espagne, la Finlande, la France, l'Irlande, l'Islande, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni et la Suède. L'objet de cette convention est de réglementer les opérations d'immersion des déchets industriels, des matériaux de dragage et des boues des égouts dans la zone de la Convention. Pour la plupart, ces opérations ont désormais cessé; l'immersion des déchets industriels cessera en 1995, celle des boues des égouts devant s'achever en 1998. Par une série de lignes directrices, la Commission poursuivra sa mission de réglementation de l'immersion des matériaux de dragage. La Convention d'Oslo réglementait aussi les opérations d'incinération en mer, cette pratique ayant été définitivement interrompue en janvier 1991.

La Convention de Paris, ou Convention de 1974 pour la prévention de la pollution marine d'origine tellurique, est entrée en vigueur en 1978. Ses Parties contractantes sont: l'Allemagne, la Belgique, le Danemark, l'Espagne, la France, l'Irlande, l'Islande, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni et la Suède. La embourg are signatories to the Convention. The Convention's aim is to prevent, reduce, and, as appropriate, eliminate pollution of the Convention area from land-based sources: discharges from rivers, pipelines, or directly from the coast. For the purposes of the Convention, discharges from offshore installations and via the atmosphere are also considered as 'land-based'.

In 1978, the Oslo and Paris Commissions established a Joint Monitoring Programme to which all Contracting Parties contribute by monitoring a number of parameters in their waters. The results of the measurements are transmitted to a data bank at the International Council for the Exploration of the Sea (ICES) where they are processed and statistically analysed. The statistics are assessed on a regular basis, and the results of the assessments are published when their quality permits.

During the past decade, the policy of the Oslo and Paris Commissions has evolved in line with the general evolution of environmental policy in Western Europe. In 1989, the Paris Commission adopted the Precautionary Principle: Contracting Parties accepted that polluting emissions of substances that are persistent, toxic, and liable to bioaccumulate should be reduced at source through the use of Best Available Technology and other appropriate measures. The use of Best Available Technology was therefore recommended for industrial processes and point sources. In 1991, the Commission adopted the principle of Best Environmental Practice for diffuse sources.

Given this evolution in policy, the Commissions decided in 1990 that it would be timely to revise the present Conventions and merge them into one new Convention: the Convention for the Protection of the Marine Environment of the North-East Atlantic.

The new Convention was opened for signature at the Ministerial Meeting of the Oslo and Paris Commissions in Paris on 22 September 1992. It was signed by all of the signatories to the Oslo and Paris Conventions (Belgium, Denmark, the European Economic Community, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom) and by Switzerland. The Convention will enter into force when it has been ratified by all of the signatories to the Oslo and Paris Conventions. It will then replace the present Conventions, but relevant decisions, recommendations, and all other agreements adopted under the present Conventions will continue to apply.

The new Convention consists of a series of provisions of general application which, among other things:

- require the application of:
  the Precautionary Principle,
  the Polluter Pays Principle (PPP),
  the Best Available Techniques (BAT) and the Best Environmental Practice (BEP), including clean technology;
- make provision for the new Commission established by the Convention to adopt binding decisions;
- make provision for the participation of observers, including non-governmental organizations, in the work of the Commission;
- establish rights of access to information about the maritime area of the Convention.

The Convention also contains a series of Annexes that deal with the following specific areas:

- the prevention and elimination of pollution from land-based sources,
- the prevention and elimination of pollution by dumping or incineration,
- the prevention and elimination of pollution from offshore sources, and
- the assessment of the quality of the marine environment.

Oslo and Paris Commissions

Commissions d'Oslo et de Paris

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Communauté économique européenne et le Luxembourg sont signataires de la Convention. L'objectif de cette convention est d'empêcher, de réduire et, s'il y a lieu, de supprimer la pollution de la zone de la Convention par des sources telluriques, à savoir les rejets par le biais des cours d'eau et des émissaires, ainsi que les rejets côtiers directs. Aux fins de la Convention, les rejets des installations en offshore ainsi que les rejets qui transitent par l'atmosphère sont également considérés comme étant de type «tellurique».

En 1978, les Commissions d'Oslo et de Paris ont mis sur pied un Programme conjoint de contrôle et de surveillance continus, auquel les Parties contractantes contribuent en contrôlant une série de paramètres dans leurs propres eaux. Les résultats des dosages sont communiqués à la banque de données du Conseil International pour l'Exploration de la Mer (CIEM) où elles sont traitées et où elles subissent une analyse statistique. Les statistiques sont systématiquement évaluées, et les résultats de ces évaluations sont publiés lorsque leur qualité le permet.

Au cours de la dernière décennie, la politique des Commissions d'Oslo et de Paris a évolué parallèlement à l'évolution générale de la politique écologique de l'Europe occidentale. En 1989, la Commission de Paris a adopté le principe de l'action de précaution, selon lequel les Parties contractantes ont accepté qu'il convenait de réduire à la source les émissions polluantes de substances persistantes, toxiques et susceptibles de bioaccumulation, ceci grâce à la meilleure technologie disponible et autres mesures adéquates. L'application de la meilleure technologie disponible a donc été conseillée pour les procédés industriels et pour les origines ponctuelles. En 1991, la Commission a adopté le principe de la meilleure pratique environnementale pour les sources diffuses.

Etant donnée cette évolution de la politique, les Commissions ont décidé, en 1990, qu'il était temps de revoir les conventions actuelles et de les fusionner en une seule et nouvelle convention, à savoir la Convention pour la protection du milieu marin de l'Atlantique du nord-est.

Cette nouvelle convention a été ouverte à la signature le 22 septembre 1992 à Paris, à la réunion ministérielle des Commissions d'Oslo et de Paris. Elle a été signée par tous les signataires des Conventions d'Oslo et de Paris (Allemagne, Belgique, Danemark, Communauté économique européenne, Espagne, Finlande, France, Irlande, Islande, Luxembourg, Norvège, Pays-Bas, Portugal, Royaume-Uni et Suède) ainsi que par la Suisse. Elle entrera en vigueur lorsqu'elle aura été ratifiée par tous les signataires des Conventions d'Oslo et de Paris. Elle remplacera alors les conventions actuelles, les décisions, les recommandations et tous les autres accords pertinents adoptés en vertu des conventions actuelles restant cependant applicables.

La nouvelle convention consiste en une série de dispositions générales qui, entre autres:

- exigent la mise en oeuvre:
  du principe de l'action de précaution,
  du principe du pollueur payeur (PPP),
  des meilleures techniques disponibles (BAT) et de la meilleure pratique environnementale (BEP), dont la technologie propre;
- stipule que la nouvelle commission créée par la Convention peut adopter des décisions de caractère juridiquement obligatoire;
- prévoit la participation d'observateurs, et notamment d'organisations non gouvernementales, aux travaux de la commission;
- crée des droits d'accès à l'information sur la zone maritime de la Convention.

La Convention comporte par ailleurs toute une série d'annexes qui traitent des secteurs particuliers ci-après:

- prévention et suppression de la pollution d'origine tellurique,
- prévention et suppression de la pollution par les opérations d'immersion et d'incinération,
- prévention et suppression de la pollution provoquée par les installations en offshore, et
- appréciation de la qualité du milieu marin.

Oslo and Paris Commissions

Commissions d'Oslo et de Paris

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Preface

The first International Conference on the Protection of the North Sea in 1984 highlighted the need for an overall assessment of the extent to which the North Sea was affected by human activities. The conclusions of the assessment would be useful in identifying those aspects of the North Sea most in need of protection. The report entitled *Quality Status of the North Sea* (1987 *QSR*) was produced in response to this need. Recognizing its close association with the English Channel and the Skagerrak, the North Sea was defined as including these two regions.

The 1987 *QSR* was followed by the *1990 Interim Report on the Quality Status of the North Sea* (1990 *QSR*), which drew attention to issues of particular concern that had arisen in the meantime, notably toxic algal blooms and a disease epidemic among populations of harbour and grey seals, and provided updated information on inputs of contaminants.

The 1987 *QSR* was largely based on national contributions of information and opinion on various topics. It was readily apparent that there were not only differences between areas but that the type and amount of information about them also differed greatly and were not always directly comparable. These factors complicated the process of reaching agreement on assessment statements. Thus it was decided that a subregional approach would be followed in the preparation of the present *North Sea Quality Status Report* (1993 *QSR*). The general procedure adopted by the North Sea Task Force was based upon advice from the ICES Advisory Committee on Marine Pollution, which had produced recommendations on how to prepare regional environmental assessments.

Inherent in the procedure is the recognition that although the North Sea is in some respects correctly regarded as a single geographical area, different parts of it exhibit different ecological characteristics. These stem from differences in latitude, in water depth, in position relative to land and sources of pollution, and in the extent of human activities. Accordingly, it was agreed that the North Sea should be divided into a number of subregions and that a separate environmental assessment report should be produced for each of them. In view of the close relationship between the Skagerrak and the Kattegat and the particular importance of the Wadden Sea, the latter were both included in the list of areas to be addressed by subregional assessment reports (*SRR*s). It was agreed that the format and content of each report would be based on a common structure, to ensure that the same topics would be covered in all reports. Each *SRR* would provide an introduction, followed by an assessment of the physical, chemical, and biological characteristics of that subregion and the extent to which they had been affected by human activities. Further, each *SRR* would conclude with a summary chapter describing issues of environmental concern, attributing causes where possible, and cataloguing uncertainties and needs for more information and better understanding.

Préface

En 1984, la première Conférence internationale sur la protection de la mer du Nord, mettait en lumière la nécessité d'une évaluation globale de la mesure dans laquelle la mer du Nord était touchée par les activités de l'homme. Les conclusions de cette évaluation seraient utiles à la définition des aspects au titre desquels la mer du Nord avait le plus besoin d'être protégée. Le rapport intitulé *L'état de la qualité de la mer du Nord* (*QSR* 1987) fut mis sur pied en réponse à cette nécessité. Etroitement liée à la Manche et au Skagerrak, la mer du Nord fut définie comme englobant aussi ces deux régions.

Le *QSR* 1987 fut suivi du *Rapport intérimaire sur l'état de la qualité de la mer du Nord* (*QSR* 1990), qui attirait l'attention sur des problèmes qui, entre-temps, avaient suscité une inquiétude particulière, et notamment les éclosions d'algues toxiques et les épidémies dans les colonies de phoques communs et de phoques gris, et qui donnait des renseignements à jour sur les apports de polluants.

Le *QSR* 1987 était en grande partie fondé sur les informations et sur les points de vue communiqués sur divers domaines par chacun des pays. Il s'avérait évident que non seulement il y avait des différences entre les zones, mais également que le type et le volume d'informations sur celles-ci différaient beaucoup eux aussi et n'étaient pas toujours directement comparables. Ces facteurs compliquaient le processus d'accord sur les évaluations. Il fut donc décidé d'adopter une stratégie sous-régionale dans la mise sur pied du *Bilan de santé de la mer du Nord* (ou *QSR* 1993). La procédure générale ainsi adoptée par le Groupe d'intervention mer du Nord se fondait sur les conseils du Comité d'avis du CIEM sur la pollution marine, lequel avait mis sur pied des recommandations sur la manière de dresser les évaluations environnementales régionales.

Dans la procédure, il est intrinsèquement reconnu que bien que la mer du Nord soit à certains égards considérée, à juste titre, comme une seule et unique zone géographique, les diverses régions de la mer du Nord présentent des différences dans leurs caractéristiques écologiques. Ces différences sont dues aux différences de latitude, de profondeur des eaux, de situation géographique par rapport aux terres et aux sources de pollution, ainsi qu'à l'ampleur des activités anthropogènes. En conséquence, il fut convenu que la mer du Nord serait divisée en plusieurs sous-régions, et qu'un rapport d'évaluation environnementale distinct serait dressé sur chacune d'entre elles. Vu les rapports étroits entre le Skagerrak et le Kattegat, ainsi que l'importance particulière de la mer des Wadden, ces régions furent inscrites sur la liste des zones devant faire l'objet de rapports d'évaluation sous-régionaux (*SRR*). Il fut convenu que la présentation et le contenu de chacun des rapports seraient fondés sur une structure commune, afin de faire en sorte que les mêmes thèmes soient abordés dans tous les rapports. Chacun des *SRR* comporterait une introduction, suivie d'une évaluation des caractéristiques physiques, chimiques et biologiques de la sous-région en cause, ainsi que de la mesure dans laquelle elle avait été touchée par les activités de l'homme. De plus, chacun des *SRR* se terminerait par un chapitre récapitulatif faisant état des problèmes écologiques, attribuant les causes lorsque possible, et énumérant les incertitudes, le besoin d'obtenir des informations complémentaires et une meilleure compréhension.

Based on the subregional assessment reports, a comprehensive *North Sea Quality Status Report* would be produced, following the same general structure but identifying common problems as well as those specific to certain subregions. The 1993 *QSR* would also draw upon information collected throughout the North Sea by various ICES and OSPARCOM working groups.

In the course of preparing the 1987 *QSR*, it had become apparent that the information available on geographical distribution of chemical contaminants and biological effects was patchy. Coverage of the coastal regions by the Joint Monitoring Group (JMG) of OSPARCOM had been reasonably comprehensive, but few samples had been taken in the more open areas of the North Sea. It was therefore agreed that immediate steps should be taken to improve this situation, and a Monitoring Master Plan (MMP) was drawn up for implementation in 1990/1991. The results of the surveys conducted under the MMP were to be assessed by appropriate ICES and OSPARCOM working groups and incorporated in the holistic report.

The 1993 *North Sea Quality Status Report* has been prepared in general accordance with the plan as originally defined, and the report that follows represents a best practical overall assessment of and a consensus opinion on the present status of the North Sea in physical, chemical, and biological terms. The assessment of the anthropogenic impact on these characteristics contained in this report will, it is hoped, provide a sound scientific basis for decisions on remedial action.

Sur la base des rapports d'évaluation sous-régionaux, un *Bilan de santé de la mer du Nord* serait dressé, rapport exhaustif ayant la même structure d'ensemble que les SRR, tout en définissant toutefois les problèmes communs aux sous-régions ainsi que les problèmes propres à telle ou telle sous-région. Le *QSR* 1993 tirerait par ailleurs parti des informations collationnées sur l'ensemble de la mer du Nord par les divers groupes de travail CIEM et OSPARCOM.

Pendant la mise sur pied du *QSR* 1987, il s'était avéré à l'évidence que les éléments d'information en possession sur la distribution géographique des polluants chimiques et des phénomènes biologiques était parcellaires. Quoique la couverture des régions côtières par le Groupe conjoint de contrôle et de surveillance continus (JMG) d'OSPARCOM ait été raisonnablement complète, peu d'échantillons avaient été prélevés en haute mer du Nord. Il fut donc convenu que des mesures immédiates devaient être prises pour remédier à cette situation, et l'on mit sur pied un Plan directeur de surveillance (MMP) devant être mis en oeuvre en 1990/1991. Les résultats des études réalisées dans le cadre du MMP devaient être évalués par les groupes de travail CIEM et OSPARCOM correspondants, et intégrés au rapport global.

Le *Bilan de santé de la mer du Nord* (1993) a été dressé, d'une manière générale, dans les conditions prévues par le plan initial, et le rapport qui suit constitue la meilleure évaluation pratique globale ainsi qu'un consensus d'opinions sur l'état actuel de la mer du Nord, sur les plans physique, chimique et biologique. L'évaluation de l'impact anthropogène sur les caractéristiques reprises dans le rapport constituera, espère-t-on, une base scientifique saine permettant de prendre des décisions sur les mesures correctives à cet égard.

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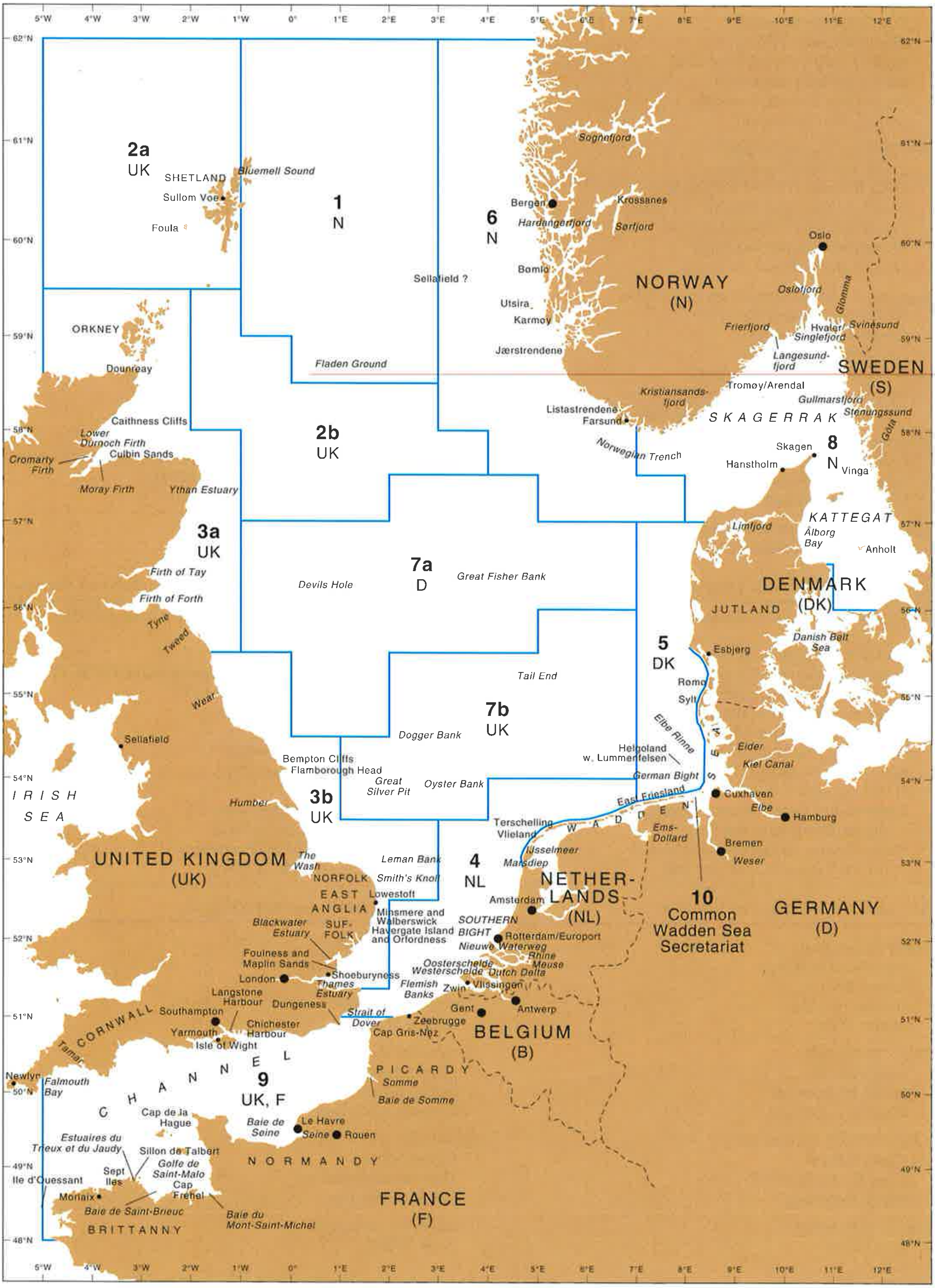


Figure 1-1. Boundaries of the North Sea as defined by the North Sea Task Force. Numbers identify subregions (see Box 1-1). Initials in subregions indicate the lead country responsible for the relevant subregional report.

CHAPTER

1

General description of the North Sea

1.1.

Introduction

This introductory chapter defines the principal geographical characteristics of the North Sea and provides an outline, in very broad terms, of the wide range of human activities on, in, and around the sea. The aim is to set the scene for the more detailed descriptions in Chapters 2–5 of the physical, chemical, and biological characteristics of the area and the impact man's activities have had and are having upon them.

The 1987 *QSR* drew attention to the wide variety of North Sea coastal types in terms of structure and form, and the considerable variations in ecology that are found as a consequence. Regarding the human uses of the marine ecosystem, that report drew particular attention to the fact that many large towns and major and long-established industries around the North Sea emptied their wastes into the sea by way of rivers and direct discharges, as well as through atmospheric inputs. It was further noted that the coastal zone was also used intensively for recreation, such as bathing and sailing, and that these activities had local impacts.

When the 1987 *QSR* was produced it was considered that there was a reasonable understanding of the physical conditions of the North Sea. However, information on certain principles of oceanography needed to be improved and, as further advances in modelling studies were made, existing knowledge was seen as likely to expand. The biological impacts of human activities were also seen as difficult to assess, and there was an incomplete picture of the distribution of contaminants. This chapter refers to all the physical features and activities that need to be taken into account in assessing the present quality status of the North Sea.

Table 1·1. Average sea area, sea depth, and volume of NSTF subregions.

NSTF subregion	Area ‡¶ km^2	Depth ‡ m	Volume ¶ km^3
1*	83 000	158	13 100
2a*	58 000	547	31 700
2b	52 000	100	5 200
3a*	45 000	61	2 800
3b	41 000	40	1 600
4	46 000	28	1 300
5	32 000	23	700
6*	77 000	207	16 000
7a	99 000	67	6 600
7b	74 000	39	2 900
8	54 000	144	7 800
9	77 000	53	4 100
10†	7 950	0–10	15–30
Total	745 950		93 830

* Definitions of Subregions 1, 2a, 3a, and 6 differ from those given in ICES (1983).
† Wadden Sea (Subregion 10): volume at low tide, 15 km^3; at high tide, 30 km^3.
‡ Areas and depths calculated from a numerical model with a nominal 35 km grid.
¶ Accuracy approximately 5% for areas and 10% for volumes.

1.2.

Physical geography

Definition and description of the area

The North Sea is situated on the continental shelf of northwest Europe. It opens into the Atlantic Ocean to the north and, via the English Channel (subsequently referred to as 'the Channel'), to the southwest, and into the Baltic Sea to the east. Accordingly, for the purposes of the North Sea Task Force, the 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 Kattegat between Sweden and Denmark (Figure 1·1 and Box 1·1). The North Sea area considered in this report has a surface of about 750 000 km^2 and a volume of about 94 000 km^3. Details for the various parts of the North Sea are given in Table 1·1.

Box 1·1. *Subdivision of the North Sea into subregions*

The subdivision of the North Sea by the North Sea Task Force into subregions takes into account both hydrographic and biological information.

The NSTF subregions are derived from boxes that were delimited by ICES (ICES, 1983) in order to simplify the calculation of flushing times in the North Sea. Their locations are shown in Figure 1·1, and their main water characteristics are listed below:

Subregion 1. Slow-moving water of recent Atlantic origin. Summer stratification.

Subregion 2. Fairly rapid water movement.
2a. Water of Atlantic origin with a mixture of coastal water. Source of Atlantic inflow into the North Sea.
2b. Fairly rapid water movement of mixed oceanic–coastal waters (Fair Isle Current). Only partly stratified in summer.

Subregion 3. Slow-moving southerly drift. Transient stratification. Fresh water content increasing southwards.
3a. Deeper water (up to 50 m).
3b. Shallower water (less than 50 m).

Subregion 4. Inflow of Channel water, mixed with coastal water. Strong horizontal gradients of salinity. Vertical stratification only close to the coast.

Subregion 5. Northward drift. Area of pronounced fronts between North Sea and coastal water. Coastal water with some stratification.

Subregion 6. Surface layers: northward movement of Norwegian coastal water and Baltic outflow with strong mesoscale stratification. Deeper layers: laterally inhomogeneous, with southerly flow in the west (water of recent Atlantic origin) and northerly flow in the east (mixed water masses). Sedimentation area of the North Sea.

Subregion 7. Water moving in variable directions, with slow net movements. Pronounced summer thermocline. Central North Sea water mass. This water mass shows strong interannual and decadal variations due to changing Atlantic flow.
In summer 7a and 7b are two separate areas below the thermocline, north and south of the Dogger Bank.

Subregion 8. Mixing area of continental coastal water, central North Sea water, Baltic outflow water, and water of recent Atlantic origin inflowing in the deeper layers. Strong, persistent halocline above the Norwegian Deep. In the northeastern part: Skagerrak type with cyclonic movement. Main sedimentation area of the North Sea.

Subregion 9. Slow-moving easterly drift of water of recent Atlantic origin. Strong tidal currents. Transient stratification. Fresh water content of the coastal water increasing eastwards (coastal flow along the French coast in the western Channel).

Subregion 10. Wadden Sea: very shallow, mostly intertidal area.

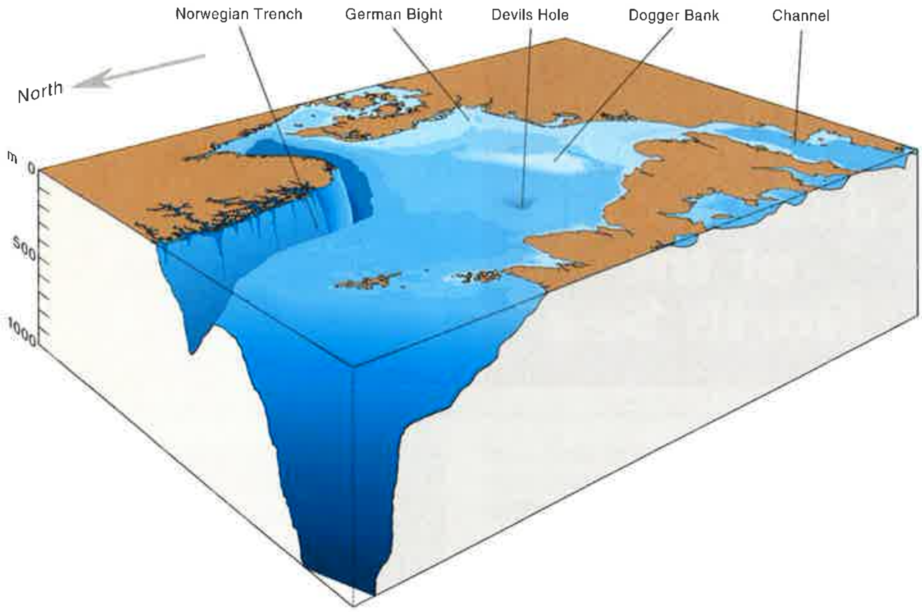


Figure 1·2. Conceptual view of the bottom of the North Sea as seen from the northwest.

Figure 1·3. North Sea sediment types. Named locations are areas of mud and sandy mud (after Eisma, 1981).

The depth of the North Sea (Figure 1·2) increases towards the Atlantic Ocean to about 200 metres at the edge of the continental shelf. Features of the seabed, such as the Norwegian Trench with a maximum depth of 700 m, and its characteristics (Figure 1·3), including sandy gravel deposits, reflect the fact that the North Sea has been affected by glaciation several times in geological history. In the relatively shallow Southern Bight, strong tidal currents and wave action have swept the glacial and fluvial sandy sediments into elongated sand waves and ridges. Mud deposition characterizes deeper areas such as the Oyster Ground, Elbe postglacial valley, Skagerrak, and Norwegian Trench. The Channel is relatively shallow and deepens gradually from about 30 m in the Strait of Dover to about 100 m in the western part. Seabed topography shows evidence of river valley systems that were carved into the seabed during glacial periods when the sea level was lower.

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. As a result the North Sea climate is characterized by large variations in wind direction and speed, a high rate of cloudiness, and relatively high precipitation. Rainfall data (Figure 1·4) (Hardisty, 1990; Barrett *et al.*, 1991; ICES, 1983) show precipitation ranging between 340 and 486 mm per year, with an average of 425 mm per year. High levels of precipitation occur along the Norwegian coast (about 1000 mm per year) as a result of wind-forced uplift of moist air against high, steep mountain ranges. The estimated net input of fresh water by precipitation (minus evaporation) to the North Sea (excluding the Channel, the Skagerrak, and the Kattegat) is about 86 km^3 per year (ICES, 1983).

There is a lack of extreme water temperatures throughout the area. In the course of a year the greatest difference in temperature occurs in the German Bight (minimum and maximum water temperatures of 0°C and 21°C; see also Chapter 2). The differences in temperature and the variations in salinity encountered in the North Sea are greater than those found in the open North Atlantic at similar latitudes, a condition attributable to the semi-enclosed nature of the North Sea.

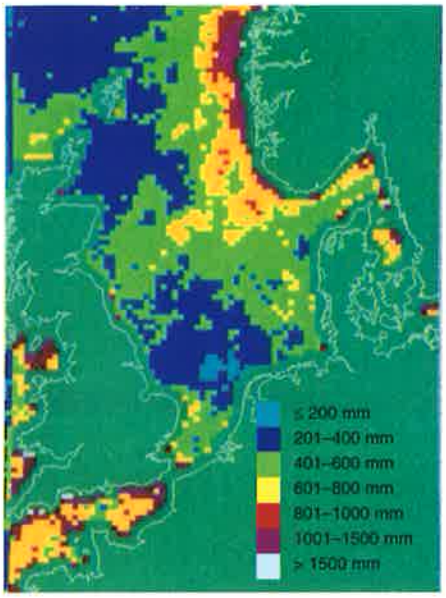


Figure 1·4. Mean annual rainfall over the North Sea estimated from Nimbus-7 passive microwave imagery, calibrated by United Kingdom radar for 1978–1987 (from Barrett *et al.*, 1991).

Physical geography of land areas bordering the North Sea

River systems and catchment areas

River systems that discharge into the North Sea (Figure 1·5) have a total catchment area of about 850 000 km^2. The annual input of fresh water from these river systems is of the order of 300 km^3, but the run-off is highly variable from year to year (Table 1·2), which is of importance for the transport of contaminants. Melt water from Norway and Sweden constitutes about one third of the total run-off. The catchment areas of the rivers Elbe, Weser, Rhine, Meuse, Scheldt, Seine, Thames, and Humber in particular are densely populated, highly industrialized, and intensively farmed. These river systems are thus among the largest sources of contaminants and nutrients flowing into the North Sea (see also Chapter 3).

Coastal characteristics

As a result of differences in geology and vertical tectonic movements, the coastlines of the North Sea display a large variety of landscapes. The northern coastlines show vertical uplift owing to the disappearance of the weight of ice after glaciation. The coastlines of Norway and northern Scotland are mountainous, with many rocky, isolated islands, and are often dissected by deep fjords.

The coasts of northern England and Scotland feature cliffs of various sizes, with or without pebbly beaches, but also with river valley intersections. From the Strait of Dover to the Danish west coast, sandy beaches and dunes prevail, with numerous estuaries (Scheldt, Rhine, Meuse, Elbe, and Weser) and the tidal inlets and islands of the Wadden Sea. This area displays signs of slow subsidence on a geological time scale. In Denmark large lagoon-like areas exist behind long, sandy beaches. The coastline of southeast England along the Channel is dominated by low cliffs and flooded river valleys. The French side of the Channel, from east to west, includes maritime plains and estuaries, cliffs, and the rocky shore of Brittany.

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

Estuaries and wetlands

Estuarine and wetland habitats occur at the transition between river basins and the open North Sea. These areas, which are shallow and have an intertidal regime, have a high natural productivity that in some cases is enhanced by an anthropogenic supply of nutrients carried by the rivers (see also Chapters 3, 4, and 5). The richness of the benthic life favours high numbers of feeding waterfowl: resident, overwintering, and migratory. These areas are also important as nurseries for juvenile fish, and the intertidal shoals are attractive 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. Important estuaries and wetlands are found in the Wadden Sea, the Wash in England, the Dutch Delta coast, the Limfjord in Denmark, and the Channel estuaries along the coasts of France and England.

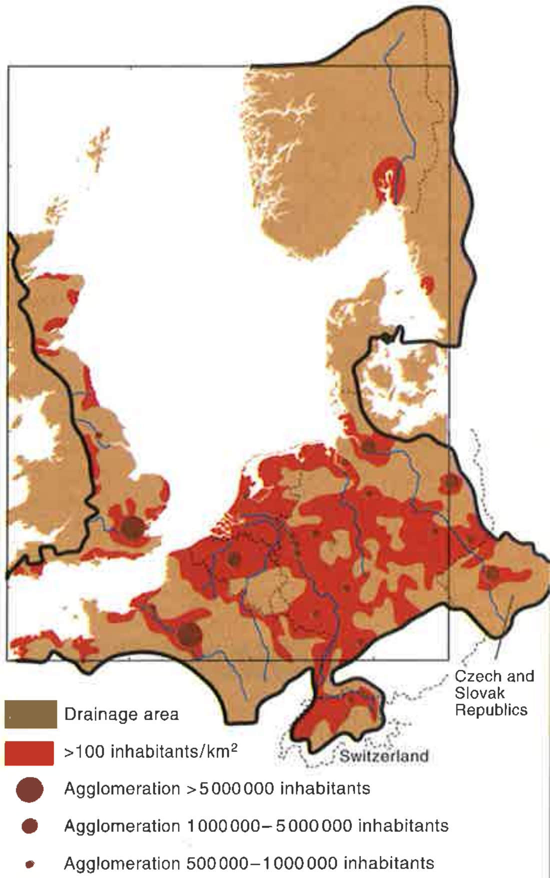


Figure 1·5. Catchment area of the North Sea showing main river systems and areas of high population density (from Grote Bosatlas, 1988).

Table 1·2. Mean annual river run-off to the North Sea for NSTF subregions.

Area	Subregion	Run-off km^3/year	Catchment area km^2
Norwegian coast	6	58–70	45 500
Skagerrak and Kattegat coasts	8	58–70	102 200
Danish and German coasts (including Danish and German Wadden Sea*)	5+(10)	32	219 900
Dutch and Belgian coasts (incl. Dutch Wadden Sea*, Rhine, Meuse, Scheldt)	4+(10)	91–97	221 400
English and French Channel coasts (including Seine)	9	9–37	137 000
English east coast (including Tyne, Tees, Humber, Thames)	3b	32	74 500
Scottish coast (including Forth)	3a	16	41 000
Total for NSTF area		296–354	841 500
*Total Wadden Sea region	10	60	230 059

1.3 Demography

Approximately 164 million people live within the catchment area of the North Sea (Figure 1·5, Table 1·3). In addition about 90 million people live in the catchment areas of rivers that flow into the Baltic Sea. Heavily populated areas are found in the river basins of the Elbe, Weser, Rhine, Meuse, Scheldt, Seine, Thames, and Humber. The highest population densities occur in the Netherlands, Belgium, and parts of the United Kingdom and Germany, with maximum densities on the coastline exceeding 1000 inhabitants per km^2 in the Netherlands and Belgium. In contrast, along the

Table 1·3. Estimated population of the catchment area of the North Sea as defined by the NSTF.

Country	Population in North Sea catchment area
Belgium and Luxembourg	10 000 000
Czech and Slovak Republics	5 000 000
Denmark	2 000 000
France	20 000 000
Germany	70 000 000
Netherlands	16 000 000
Norway	3 000 000
Sweden	3 000 000
Switzerland	5 000 000
United Kingdom	30 000 000
Total	164 000 000

coastlines of Norway and Scotland, densities of fewer than 50 inhabitants per km^2 are common. Total indigenous population figures in North Sea countries are stable and not expected to change in the next few decades, subject to a possible effect of the migration fluxes to Western Europe. However, within these countries considerable migration may occur as a result of economic and political developments, which may affect population densities in particular catchment areas. On a shorter (seasonal) time scale the variation in population due to tourism and recreation on the coast can be very substantial; in popular resorts the population may be ten times larger in summer than in winter.

1.4.

Uses and functions of the North Sea

Political aspects, economic zones

With respect to the exploitation of its natural resources (oil, gas, sand, gravel) a coastal state enjoys sovereign rights on its continental shelf (the seabed and subsoil) beyond the territorial sea. Following the adoption of the Geneva Convention on the Continental Shelf (1958) by a majority of North Sea States, the delimitation of the continental shelf of the North Sea was agreed by opposite and adjacent states bordering the North Sea (Figure 1·6). No agreement yet exists for the boundary between the Belgian and Dutch parts of the continental shelf.

On 22 September 1992 the Ministers of the North Sea States and the Representative of the Commission of the European Communities (CEC) issued a joint declaration on the coordinated extension of jurisdiction in the North Sea, by the establishment of Exclusive Economic Zones (EEZ) or alternative ar-

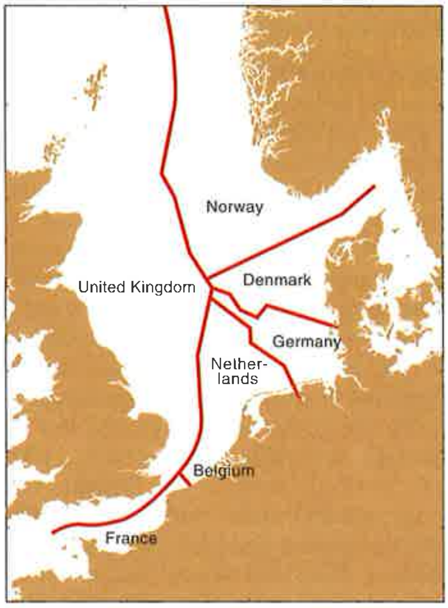


Figure 1·6. North Sea continental shelf delimitation boundaries determined for purposes of establishing seabed mineral rights (after ICONA, 1992).

rangements. They agreed that coastal state jurisdiction should be increased to the full extent permitted by the rules of international law in order to prevent, reduce, and control pollution of the marine environment. The existence of EEZs in the North Sea will enable coastal states to adopt certain laws and regulations giving effect to generally accepted international rules and standards for the prevention, reduction, and control of pollution from vessels, and to take other measures concerning the exercise of jurisdiction. This will result in a better and more effective enforcement of international rules for environmental protection.

The management of fishery resources in the North Sea is subject to European Community (EC) regulations developed on the basis of scientific advice from ICES (see 'Fishing', p. 13). Since Norway is not an EC member state, the access of EC fishing vessels to Norwegian waters and reciprocally of Norwegian vessels to EC waters is regulated in a specific fisheries agreement. The Norwegian fisheries zone corresponds to the Exclusive Economic Zone and includes a large part of the North Sea and the Skagerrak. In addition to the EC regulations, national measures in territorial waters may exist regarding national fishery activities, including those relevant to shellfish or the preservation of national natural resources.

The North Sea is a very important area for shipping. The International Maritime Organization (IMO), a specialized agency of the United Nations, deals with the safety of shipping and the protection of the marine environment against the harmful effects of shipping by means of numerous agreements and conventions. The most notable of these are the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), which relates to operational discharges from ships, and the International Convention for the Safety of Life at Sea (SOLAS 74/78), which relates to ship construction and equipment, the safety of navigation, and the carriage of dangerous goods. Other conventions and IMO regulations deal with the prevention of accidental pollution through specific ship design (double hull or alternative options presenting the same degree of protection) and routing measures such as traffic separation schemes and avoidance of certain areas. In addition, the EC has introduced specific measures to enhance the protection of the North Sea and to protect vulnerable coastal areas against accidental oil pollution.

Activities

Tourism and recreation

On North Sea coasts tourism has been an important activity ever since increased wealth and the expansion of the railway system generated large-scale holiday resorts in the nineteenth century, followed by substantial shoreline development. Tourism continues to be a high growth sector, accounting for 26% of export of services and 14% of services employment among member countries of the Organisation for Economic Cooperation and Development (OECD), and much of this growth is focused on the coast. The coastline and the land adjacent to it are therefore highly valuable resources, attractive for their natural beauty, but subject in many areas to intense development pressure, much of it of a seasonal character, which can pose a serious threat to their well-being.

Coastal tourism involves a wide range of activities, from waterborne recreation such as sailing and bathing, to camping, caravanning, golf, and the establishment of retirement homes and other developments attracted to a coastal location (Box 1·2). These in turn may have major implications for the infrastructure, with a need for increased transport capacity, development land, coastal defence, water supply, and sewage and waste disposal facilities, as well as generating an increased contaminant load through vehicle and waste emissions. Some coastal developments may interfere with natural sea defences such as sand dunes and affect dynamic coastal processes such as sand movement along the shoreline and into adjacent waters. Coastal developments also create nuisances such as noise and artificial illumination at night.

Box 1·2. *Tourism on the coasts of the North Sea*
Around the North Sea development pressures and problems vary, and while some natural coastal landscapes receive a high degree of planning protection, others are already intensively developed. In Norway tourism is highly concentrated in the Oslofjord–Skagerrak region, where building of holiday homes and sailing are major activities (2.4 million overnight stays in 1990). Local land-use planning aims to set aside separate zones for open-air recreation, special purposes, and common use. On Swedish coasts similar issues arise. In Denmark, on the west coast of Jutland, tourism has become a more important industry than fishing, with 9.6 million overnight stays in 1991, an increase of just under 50% since 1989, but clearly such figures fluctuate in response to weather and other factors. In the Netherlands, the North Sea coast is the most important recreational area, with about 38 million visitors annually. In areas such as the Wadden Sea (around 30 million overnight stays) important decisions must be made regarding the promotion of tourism, the protection of conservation interests, and the types of coastal defence that may have significant ecological effects on, for example, the salinity of an estuary. Along the Belgian coast, 16.2 million overnight stays and about 20 million one-day visitors were recorded in 1990. Along the French coast new initiatives are being taken to protect natural landscapes and to preserve an undeveloped coastal strip. The Conservatoire de l'Espace Littoral et des Rivages Lacustres is in charge of the definitive protection of natural coastlines of high environmental importance. At present, the total extent of the coastline under its protection is 6400 hectares. In the United Kingdom the most popular holiday resorts are on the Channel coasts and in East Anglia, areas which receive 19 million holiday-makers annually (excluding day visitors). Sailing is a major recreational activity, with a total of 150 000 craft (over 6.5 metres in length) moored in United Kingdom coastal waters. Much of the coastline receives a high degree of protection under planning law and through ownership by agencies such as the National Trust, but difficult issues remain, owing to competition for coastal land for the development of caravan and camping sites, golf courses, and other leisure activities.

Fishing

Fish

Traditionally, fishing has been an important activity in all the countries bordering the North Sea. Figure 1·7 shows the landings of different species by region in 1990, amounting to about 2.4 million tonnes. Figure 1·8a shows the trend in total landings between 1903 and 1988 for the North Sea (excluding the Channel, the Skagerrak, and the Kattegat). The landings of fish can be split into four broad categories: roundfish (e.g., cod), flatfish (e.g., plaice), and pelagic (e.g., herring) species that are used for human consumption, and fish that are processed for fish meal and oil (Norway pout, sprat, and sandeel) (see also Chapter 5). Until the late 1950s the catch of roundfish and flatfish species remained fairly stable. In the 1960s the catch of roundfish increased, partly in response to increases in stock size. An increase also occurred in the landings of pelagic fish in the mid-1960s following the introduction of new fishing techniques, but this was succeeded by a sharp decline after only three years. Landings of roundfish and flatfish species peaked some years later, but also fell subsequently. In Figures 1·8b, c, and d, the data on landings are extended to 1990 for three individual species (herring, cod, and plaice) and show the recovery of herring landings after the overexploitation of the late 1970s. Landings in the industrial fisheries using small-mesh trawls (see also Chapter 5) reached a plateau in the 1970s, then fell to a lower level where they have remained relatively stable. The species caught by industrial fisheries include three target species (Norway pout, sandeel, and sprat; Table 1·4) and a by-catch of human consumption species (particularly herring and whiting in recent years), which amounted to about 13% of the total for industrial fisheries in the years 1987–1991. In addition to the landings by industrial trawlers, variable quantities of fish (e.g., herring and mackerel) that are surplus to market requirements are landed in other fisheries and used for reduction. Industrial landings are shown in Figures 1·8e and f, and combined industrial and consumption landings per country in 1988 are summarized in Table 1·5.

Shellfish

The major commercial shellfishery in the North Sea is for Norway lobster (*Nephrops norvegicus*). Fishing takes place from the Botney Gut–Silver Pit area in the south to the Fladen Ground in the north and provides Belgian, Danish, and United Kingdom vessels with a catch ranging from 6000 to 11 000 tonnes per year. An offshore fishery for

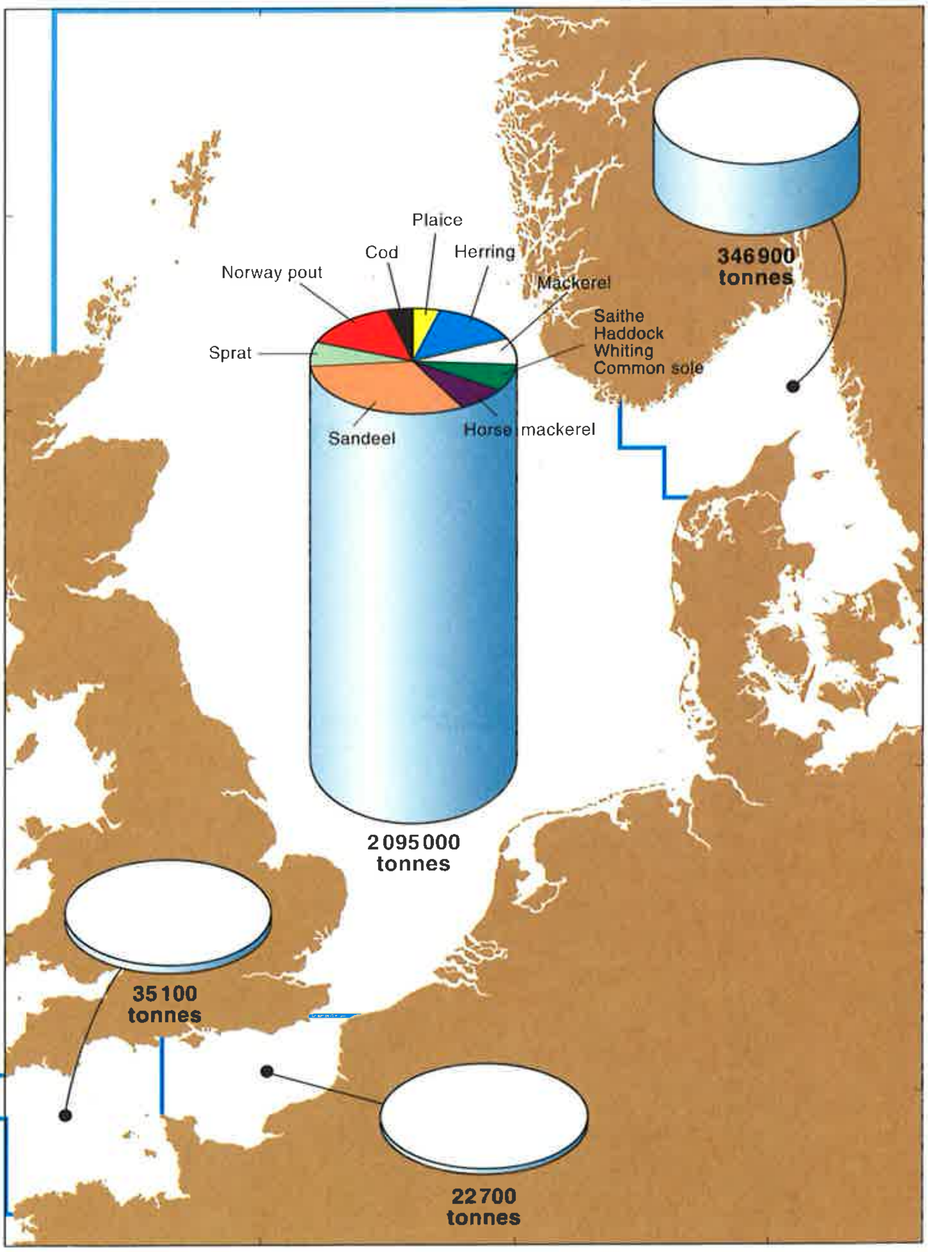


Figure 1·7. Fish landings from the North Sea in 1990. Source of data: ICES (1993).

Table 1·4. Annual landings (thousands of tonnes) from the industrial fisheries for Norway pout, sandeel, and sprat from the North Sea, 1974–1991. For 1991 the landings are also given by quarters. Source: ICES (1992a).

	Major fisheries							
	Clupeoids			Gadoids		By-catch of protected species‡	Other species¶	Total¶
Year	Sandeel	Sprat†	Herring	Norway pout	Blue whiting			
1974	525	314	–	736	62	220	–	1 857
1975	428	641	–	560	42	128	–	1 799
1976	488	622	12	435	36	198	–	1 791
1977	786	304	10	390	38	147	–	1 675
1978	787	378	8	270	100	69	–	1 612
1979	578	380	15	320	64	77	–	1 434
1980	729	323	7	471	76	69	–	1 675
1981	569	209	84	236	62	85	–	1 245
1982	611	153	153	360	118	57	24	1 476
1983	537	88	155	423	118	38	42	1 401
1984	669	77	35	355	79	35	48	1 298
1985	622	50	63	197	73	29	66	1 100
1986	848	16	40	174	37	22	33	1 170
1987	825	33	47	147	30	24	73	1 179
1988	893	87	179	102	28	54	45	1 388
1989	1 035	63	146	162	28	40	59	1 533
1990	590	77	115	140	22	61	40	1 039
1991*	842	110	131	155	28	45	38	1 349
1st Quarter	30.8	2.0	12.5	43.0	4.6	5.7	12.9	111.6
2nd Quarter	585.1	0.1	11.4	17.9	17.5	5.7	7.0	644.9
3rd Quarter	221.8	67.5	79.7	35.1	3.7	21.1	11.3	440.2
4th Quarter	4.2	38.2	27.4	58.6	2.3	12.1	8.2	151.0
Mean 1974–90	678	224	71	322	63	80	48¶¶	1 287¶¶

* Preliminary figures. † Includes human consumption landings. Quarterly data for Denmark, Norway, and United Kingdom only. ‡ Haddock, whiting, and saithe which are protected by relevant regulatory measures. ¶ Data for other species not available for 1974–1981. ¶¶ Mean 1982–1990.

deepwater pink shrimp (*Pandalus borealis*) by Danish, Norwegian, Swedish, and United Kingdom vessels produces 2500 to 13 900 tonnes annually.

Mussel, whelk, winkle, cockle, crab, lobster, and shrimp fishing activities are concentrated in the coastal zones and estuaries. Since 1988 mortality of birds has been observed in the Wadden Sea which has been attributed to overexploitation of mussel and cockle stocks. In 1991/1992 regulations were imposed which have considerably restricted mussel and cockle landings in the Wadden Sea.

The production of scallops in the Baie de Saint-Brieuc in northern Brittany fell from 10 000–12 000 tonnes per year in 1970 to 2000 tonnes per year in 1991, but by 1992 it had increased to 4000 tonnes per year.

Fisheries for cockles, mussels, and shrimps are a feature of the Wash and Thames estuaries; 1300 to 6500 tonnes of mussels per year are taken along the whole east coast of England. There are also fisheries for cockles, mussels, and shrimps along the French coast of the Channel, where cockles alone yield an average of 5000 tonnes per year.

Scallops have been fished for some years around Shetland and Orkney and

Table 1·5. Landings (tonnes) of fish and shellfish from the North Sea, Kattegat and Skagerrak, and Channel by country in 1988.

	Species	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK	Other	Total
North Sea	Herring	4	94 545	9 604	15 221	72 500	221 246	2 444	71 257	1 580	488 401
	Mackerel	22	23 636	2 306	224	2 560	58 317	437	1 002	–	88 504
	Gadoids	8 014	86 779	50 847	27 850	23 301	49 519	2 039	205 429	2 117	455 895
	Sandeels	–	776 671	–	–	–	191 488	–	10 866	15 531	994 556
	Other industrial	–	210 566	2	–	371	67 263	–	583	1 336	280 121
	Other fish	16 241	126 417	7 195	5 027	101 208	53 655	122	63 107	256	373 228
	Total	24 281	1 318 614	69 954	48 322	199 940	641 488	5 042	352 244	20 820	2 680 705
	%	0.9	49.2	2.6	1.8	7.5	23.9	0.2	13.1	0.8	–
	Crustaceans	1 352	4 201	78	14 274	2 592	5 198	220	14 382	–	42 297
	Molluscs	495	64 117	94	30 848	–	9	–	25 813	–	121 376
	Total	1 847	68 318	172	45 122	25 92	5 207	220	40 195	0	163 673
	%	1.1	41.7	0.1	27.6	1.6	3.2	0.1	24.6	–	–
Kattegat and Skagerrak	Herring	–	59 752	–	–	–	11 895	106 444	–	–	178 091
	Mackerel	–	780	–	–	–	359	673	–	–	1 812
	Gadoids	66	132 828	–	–	112	6 226	5 905	–	–	145 137
	Sandeels	–	22 365	–	–	–	165	–	–	–	22 530
	Other industrial	–	102 568	–	–	–	1 677	5 373	–	–	109 618
	Other fish	798	29 359	–	–	2 160	1 530	2 977	–	–	36 824
	Total	864	347 652	0	0	2 272	21 852	121 372	0	0	494 012
	%	0.2	70.4	–	–	0.5	4.4	24.6	–	–	–
	Crustaceans	3	7 096	–	–	–	3 161	2 221	–	–	12 481
	Molluscs	–	5 690	–	–	–	–	6	–	–	5 696
	Total	3	12 786	0	0	0	3 161	2 227	0	0	18 177
	%	0.02	70.3	–	–	–	17.4	12.3	–	–	–
Channel	Herring	–	–	11 009	6	9 731	–	–	1 012	–	21 758
	Mackerel	–	–	6 424	432	1 120	–	–	14 676	–	22 652
	Gadoids	854	–	27 514	–	1	–	–	4 932	–	33 301
	Sandeels	–	–	117	–	–	–	–	–	–	117
	Other industrial	–	8 072	469	–	1	–	–	4 725	–	13 267
	Other fish	4 290	10 221	39 768	10	4 490	–	–	11 956	97	70 832
	Total	5 144	18 293	85 301	448	15 343	0	0	37 301	97	161 927
	%	3.2	11.3	52.7	0.3	9.5	–	–	23.0	0.1	–
	Crustaceans	246	–	8 073	–	–	–	–	7 017	–	15 336
	Molluscs	288	–	53 519	–	–	–	–	4 061	–	57 868
	Total	534	0	61 592	0	0	0	0	11 078	0	73 204
	%	0.7	–	84.1	–	–	–	–	15.1	–	–

Box 1·3. *Fisheries management*

Management of the fisheries in the area covered in this report is based on agreement between the European Community (EC) and Norway in the North Sea, between the EC, Norway, and Sweden for the Skagerrak and Kattegat, and on EC legislation in the Channel and to the north of Scotland west of 4°W.

In 1983 the EC adopted the Common Fisheries Policy (CFP) in order to secure the long-term rational development of the fisheries in the North Sea, and it was reviewed and modified in 1992. This review, embodied in Council Regulation (EEC) No. 3760/92 of 20 December 1992, introduced major changes in principle to the CFP, as indicated in the following extracts:

– the objective should be to provide for rational and responsible exploitation of living aquatic resources and of aquaculture, while recognising the interest of the fisheries sector in its long-term development and its economic and social conditions and the interest of consumers taking into account the biological constraints with due respect for the marine ecosystem;

– the selectivity of fishing methods should be improved with a view to optimum utilisation of biological potential and limitation of discards, for the purposes of rational and responsible exploitation of resources;

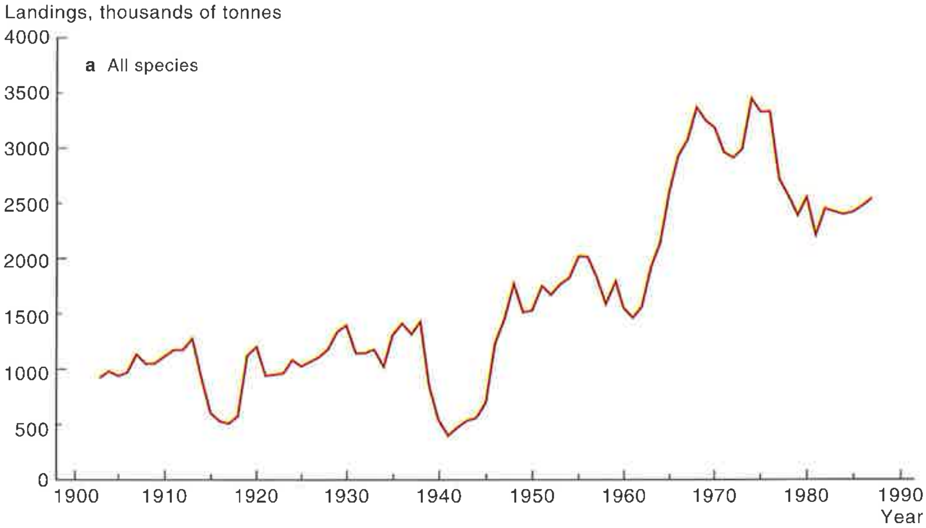
– the Council shall establish measures in order to ensure the rational and responsible exploitation of resources on a sustainable basis.

The CFP contains several measures relating to the conservation and management of fish and shellfish resources. These measures include rules on the use and allocation of resources among member states, technical conservation measures (e.g., minimum mesh sizes, minimum landing sizes of fish, and area closures), special measures for inshore fisheries, and supervisory measures. The main method for controlling fishing effort is a system of Total Allowable Catches (TACs) and quotas which put an upper limit on the landings of each stock. The TACs are fixed annually in the light of available scientific advice from the International Council for the Exploration of the Sea (ICES) and split among the countries in accordance with a set of criteria based on the principle of relative stability, which in essence translates into maintaining a fixed percentage of the TAC per stock for each country. However, as pointed out in a report from the Commission of the European Communities (1991), TACs are an indirect means of controlling fishing effort, which do not take into account the fact that large quantities of fish are discarded. The TAC system has also suffered from enforcement problems, which have resulted in a deterioration of catch statistics. To remedy these problems, new proposals to control fishing effort more directly and to introduce licensing measures have been incorporated in the 1992 review of the CFP. In addition to TACs and technical conservation measures the EC has developed guideline plans for reductions in fishing effort in its Multiannual Guidance Programme.

Commission of the European Communities (1991).

Box 1·4. *Scientific advice on fisheries management*

The scientific advice on which the Total Allowable Catches (TACs) and other conservation measures are decided is provided by the Advisory Committee on Fishery Management (ACFM) of the International Council for the Exploration of the Sea (ICES). The advice from ACFM is concentrated on stocks of commercial importance. For stocks which are thought to be in danger or expected to become so in the near future, ACFM provides advice on the measures needed to rectify the situation. For other stocks ACFM normally provides a range of options together with impact statements for each option. When the data are not sufficient to provide quantitative advice, precautionary advice may be given when requested.



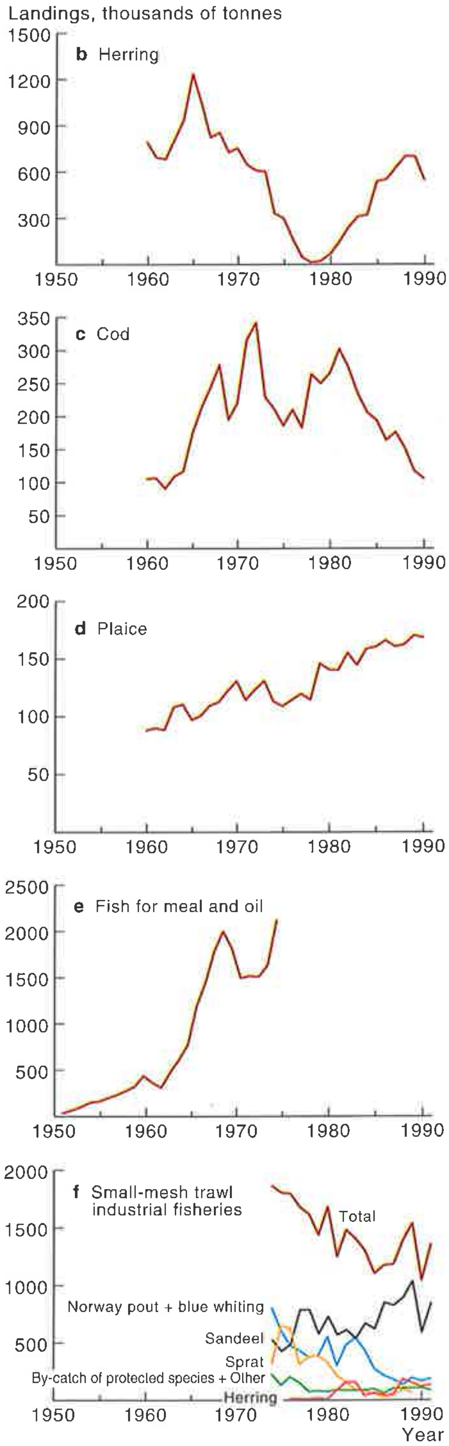


Figure 1·8. Fish landings from the North Sea.
a) Nominal catch of fish from the North Sea (excluding the Channel, the Skagerrak, and the Kattegat), 1903–1988, as officially reported to ICES.
For 1903–1972: Bull. stat. Pêches marit.
For 1973–1988: catch figures from STATLANT 27A database.
b) Landings of herring (*Clupea harengus*), 1960–1990 (from Heessen, 1988).
c) Landings of cod (*Gadus morhua*), 1960–1990 (from Heessen, 1988).
d) Landings of plaice (*Pleuronectes platessa*), 1960–1990 (from Heessen, 1988).
e) Landings of fish for reduction to meal and oil in the purse seine and small-mesh trawl industrial fisheries (from Popp Madsen, 1978).
f) Landings of fish in the small-mesh trawl industrial fisheries (from ICES, 1992a).

in the Moray Firth. Catches in this area have ranged up to a maximum of 2150 tonnes per year. In 1991 grounds to the east of Scotland were exploited for the first time, and catches exceeded 500 tonnes.

Queen scallops are fished inshore around Orkney and Shetland, with catches ranging up to 330 tonnes per year, and off the northeast coast of England, where catches amount to some 600 tonnes annually.

Management

Fisheries are managed under a system of Total Allowable Catches (TACs) established each year on the basis of scientific advice from ICES (Boxes 1·3 and 1·4), which are then divided into quotas. This system works along with a regime of technical measures such as restrictions on mesh shape and size, number of fishing days allowed at sea, and definition of areas where fishing is prohibited.

Fishing effort, which is a measure of the amount of fishing, depends on the number of vessels, their size and power, the time spent fishing, and the effectiveness of the vessels at catching the fish or shellfish in question (which is related *inter alia* to technological development). It is measured in different ways for different types of fishing gear (e.g., days at sea, days spent fishing, number of vessels, and size of gear), and no single unit is applicable in comparisons of different types of gear.

Aquaculture

Aquaculture is practised only in certain parts of the North Sea, and the statistics do not necessarily distinguish between this production and catches from wild or semi-cultivated stocks. It is mainly practised in northern waters, apart from the Wadden Sea and the northern coast of France where mussel cultivation is a major activity, and the southeast coast of England where there is a small-scale production of oysters. Mariculture in the Orkney, Shetland, and other Scottish regions produces oysters, scallops, mussels, and salmon. Figures for 1991 were 112 000 Pacific oysters, 31 000 scallops, 28 tonnes of mussels, and about 13 300 tonnes of salmon. In Norway 97% of fish from production are salmon (in 1990, 70 000 tonnes in the North Sea). Trout production on the Danish coast of the Kattegat yields about 7000 tonnes annually.

Oysters are cultivated on a small scale in several estuaries on the southeast coast of England. Oyster banks found along the coast of Normandy have been exploited for many centuries. Since the 1960s modern cultivation has extended shellfish production along the coast of Brittany. Poles for the cultivation of mussels have been erected along hundreds of kilometres in the past fifteen years. In 1990 the French production of oysters in the Channel (mainly *Crassostrea gigas*) was 41 000 tonnes, and the production of mussels was 26 500 tonnes.

Seaweeds are harvested along some parts of the United Kingdom coast and particularly along the French coast of the Channel and along the Norwegian west coast for use in the production of alginates. Although they are not strictly speaking cultivated, the industry does favour certain species of macroalgae, e.g., *Laminaria digitata* in France (57 000 tonnes per year) and *Laminaria hyperborea* in Norway (165 000 tonnes per year), and there have been some experimental introductions of species such as *Undaria pinnatifida* in an attempt to boost production.

Coastal industry

Industries of various types are located along the coast of the North Sea, especially around the Southern Bight. There are, however, no concentrations of particular types of coastal, as opposed to inland, industries. Location is as much governed by historical circumstance (e.g., local mineral deposits or a nearby town as a source of labour) as by the fact that the site is on the coast. Inputs of contaminants from inland centres of industry to the sea via the atmosphere and rivers are important and are addressed in Chapter 3.

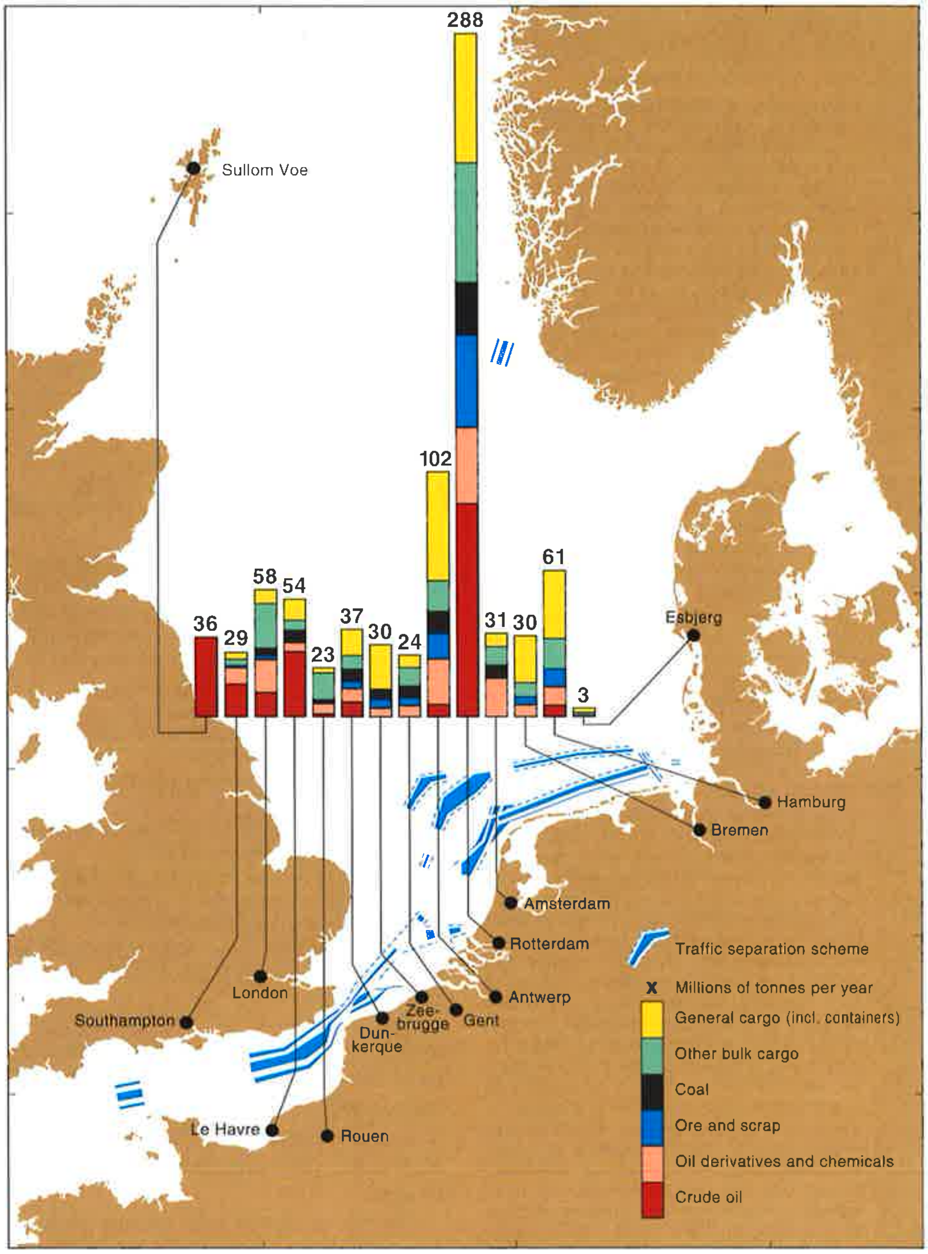


Figure 1·9. Shipping in the North Sea, showing total cargo shipments (millions of tonnes per year) in the most important ports around the North Sea in 1990 and international shipping traffic measures (after ICONA, 1992, and Port of Rotterdam Statistics, 1992).

Shipping

Traffic and cargo

The North Sea contains some of the busiest shipping routes in the world, with around 420 000 shipping movements per year within its limits. There is particularly heavy traffic through the traffic separation scheme in the Strait of Dover, with approximately 150 ships per day sailing in each direction, in addition to an average of 300 ferry crossings daily. The dredged entrance route to Rotterdam/Europort and its connecting route through the Channel permits navigation of vessels of up to 400 000 tonnes with a maximum depth of 24 m (Figure 1·9). There is also a heavy flow of shipping from the North Sea to the Baltic via the Kiel Canal, with 46 800 vessel movements in 1988, carrying 60 million tonnes of cargo. Most of the European Community's largest ports are on North Sea coasts and rivers: Hamburg, Amsterdam, Rotterdam, Antwerp, Le Havre, and London (Figure 1·9). By volume of trade, Rotterdam is the world's largest port. Rotterdam/Europort accounts for nearly half the total liquid bulk imports to North Sea ports and 30% of dry bulk, general cargo, and containers. Antwerp is the major port in Europe for handling piece goods (43.5 million tonnes, of which 16.5

million tonnes were containers in 1990). Approximately half the shipping activity in the North Sea consists of ferries and roll-on/roll-off vessels on fixed routes while, for example, in United Kingdom ports, tanker traffic represents about 10% and chemicals around 4% of ship departures.

Accidents

The Marine Safety Committee of the International Maritime Organization officially defines major marine accidents as casualties in which a ship of 1600 gross tonnes or more is lost or in which a ship of 500 tonnes or more is involved when there is loss of life. The Committee recorded 121 such accidents in 1990, ten of which occurred in the North Sea or adjacent waters. These included five cases of fire or explosion and two of vessels foundering in bad weather, while structural failure, grounding, and collision were each responsible for one loss; two of these involved oil pollution. It has been established that about 80% of accidents result from human error.

During the period 1989–1991, there were 40 accidents involving tankers in the North Sea, excluding the Channel, the Skagerrak, and the Kattegat. This represented approximately 8.6% of the world-wide total of 464 reported for the period. The incidence of major accidents (as defined by IMO) in the North Sea as a percentage of the world-wide total was very similar (8.3%).

Full data for all marine casualties in the North Sea as a whole are not published but, on the basis of the above figures and other available statistics, about 150 accidents can be expected in a typical year. Most will be relatively minor; nevertheless, many of them have a serious potential for causing marine pollution (see also Chapter 3).

Offshore industry

Oil, gas, and pipelines

The offshore oil and gas industry has become a major economic activity in the North Sea since the late 1960s. The major oil developments to date have been in the northern parts of the North Sea in the United Kingdom and Norwegian sectors (Figure 1·10). Gas deposits are exploited mainly in the shallower southern regions of the North Sea in the United Kingdom, Dutch, and Danish sectors, as well as in Norwegian waters. Although there are several gas and oil production platforms in the Wadden Sea, further exploration and exploitation are subject to tight controls, with a moratorium on drilling in the Dutch sector applying to both exploration and exploitation drilling until 1994.

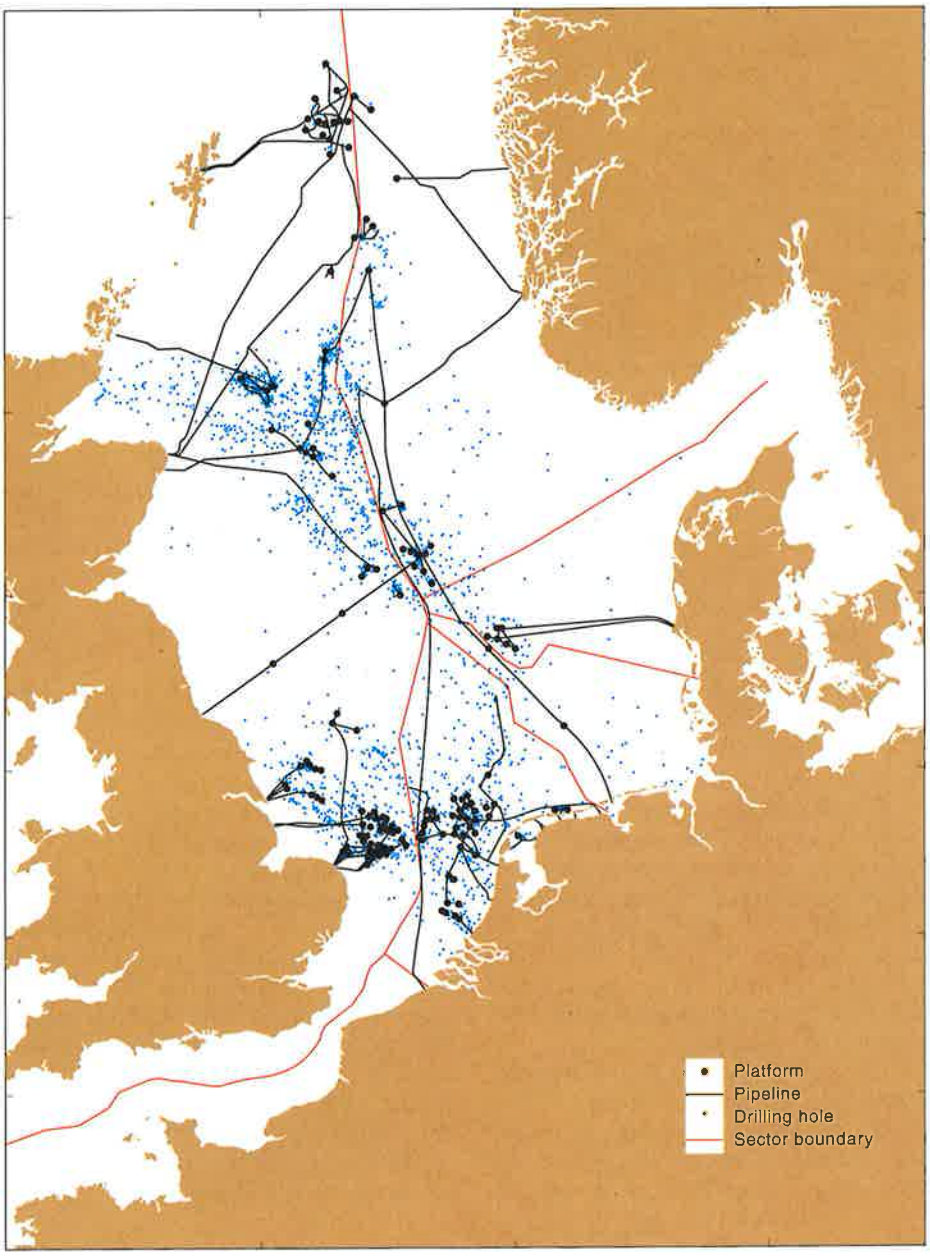


Figure 1·10. Offshore activities in the North Sea, showing oil and gas production platforms and pipelines in 1991 (after ICONA, 1992), and positions of oil wells and exploration drillings.

The 1987 *QSR* identified offshore oil and gas installations as significant sources of hydrocarbons discharged into the North Sea. The report noted the particular interest of the Paris Commission in this source of input and its effects. Since then the Paris Commission has turned its attention also to the other chemicals used and discharged in the course of offshore oil and gas exploration and exploitation. Many of these substances are used in considerable quantities, and some have undesirable characteristics (see also Chapter 3).

Table 1·6 gives the most recent information available on the size of the

Table 1·6. Gas and oil production by countries bordering the North Sea.

Country	Year	Number of platforms in production	Length of major pipelines, km	Gas production 10^9 m³/year	Oil production 10^6 t/year
Belgium	1992	0	20	0	0
Denmark	1990	30	450	5.1	6
France	1992	0	0	0	0
Germany	1987-1990	3	300	0.08	0.27
Netherlands	1992	68	2 180	17.3	1.9
Norway	1991	50	2 000	25	91
Sweden	1992	0	0	0	0
United Kingdom	1991	150	5 800	45	84
Total		301	10 750	92.48	183.17

industry. From this it can be seen that about 300 platforms produce 92.5×10^9 m^3 of gas per year and 183×10^6 tonnes of oil per year which are transported by about 10 000 kilometres of pipeline across most areas of the North Sea (Figure 1·10). This last total includes the 400 km pipeline from Sleipner in the Norwegian sector to Zeebrugge in Belgium which came into operation in 1993.

Sand and gravel extraction

The North Sea is an important source of mineral aggregates, especially for the United Kingdom, Denmark, and the Netherlands. Marine aggregates are used for construction, infill, and beach nourishment purposes. Since 1985 there has been a growing demand for construction and infill materials. Combating beach erosion by beach nourishment is also becoming a more common practice. On the other hand, land-based extraction has become less acceptable as a means of filling this growing need. As a result of these developments, both in demand and availability of supply, the United Kingdom, Denmark, and the Netherlands doubled their combined marine extraction quantity to about 34 million m^3 per year between 1985 and 1989 (Table 1·7). Aggregate extraction in Germany has been used only for beach nourishment projects; a single project accounted for the two million cubic metres extracted in 1989.

In the Dutch sector of the North Sea, extraction landward of the 20 m depth contour is not licensed owing to ecological and coastal defence considerations. Extraction is combined with maintenance dredging of navigation channels as much as possible.

In certain areas natural sources of calcium carbonate are exploited for construction and other uses. In the Wadden Sea up to 120 000 m^3 of shells are extracted annually, and calcareous algae (maerl) is exploited on a smaller scale off the southwest coast of England. A larger quantity of maerl (370 000 t) is extracted from accumulations off the French coast.

Table 1·7. Quantities of sand and gravel taken from marine sources in 1989. Source: ICES (1992b).

Country	Quantity of sand and gravel, m^3
Belgium	970 000
Denmark	7 700 000
France	1 000 000
Germany	2 000 000
Netherlands	9 200 000
Norway	66 000
Sweden	66 000
United Kingdom	12 900 000
Total	33 902 000

Military activities

Military uses of the sea in peacetime constitute a very small part of the seaborne and coastal activities around the North Sea. Deeper northern waters are more suitable for naval and military exercises than the shallow and more densely trafficked Southern Bight. In some areas weapons testing and firing ranges occupy part of the coastal strip, and uses such as these impose restrictions on public access to ranges and training grounds, at least at certain times.

Examples of peacetime military activities that take place in the North Sea include fishery protection patrols carried out by the navies of several North Sea States, national and North Atlantic Treaty Organization (NATO) exercises involving aircraft, ships, and submarines, and, in particular, patrols by Mine Counter-Measure vessels.

NATO air forces use the airspace over the North Sea for routine training. General training exercises take place at various heights, as well as more specialized training, such as air-to-air refuelling, air combat manoeuvring, and joint exercises with naval forces. Close to the coast, aircraft use a number of air weapons ranges to practise weapon delivery, and helicopters are engaged in search and rescue training. Other examples of military coastal activity include the weapons testing range at Shoeburyness in the outer Thames Estuary and firing ranges and exercise areas in the Dutch Wadden Sea around the island of Vlieland and on the island of Rømø off the west coast of Denmark.

Waste inputs

The North Sea is affected by a wide range of human activities – industrial, domestic, and agricultural – which introduce material through rivers, rainfall, and direct discharges via drainage systems, outfalls from sewage works, effluents from industry, and dumping at sea. This material may include nutrients such as nitrate and phosphate; metals such as copper, zinc, cadmium, and mercury; and organic compounds. Inputs of these substances are described in Chapter 3. Sewage effluents from almost all coastal towns around the North Sea are discharged into the nearest estuary or coastal water. The level of treatment differs considerably from country to country.

Incineration of wastes on special incinerator vessels in the North Sea ended in 1991, and in recent years the use of dumping at sea as a means of disposing of industrial waste has declined substantially. The last few licences for disposal at sea of liquid industrial waste and fly ash from the United Kingdom expired in early 1993. The United Kingdom is also committed to a programme to phase out the disposal of sewage sludge at sea by the end of 1998.

Disposal of dredged material

Material dumped at sea consists principally of dredged material removed to keep navigation channels clear (maintenance dredging) or removed during the construction of new harbours or other coastal engineering projects (capital dredging). Between 1985 and 1987, an average of 83 million tonnes of dredged material were dumped at sea each year in the North Sea (North Sea Task Force area). In the period 1988 to 1990 the average amount dumped per year in the same area was 61 million tonnes. Maintenance dredging is dependent on a variety of factors such as port use and natural variations in transport and sedimentation of fluvial and marine sediments, thus the quantities of material dumped may vary from year to year. In addition, the scale of capital dredging programmes, and hence the quantity of material for disposal, varies from year to year. Some dredged material such as sand can be used for beneficial purposes, e.g., as fill material and for beach nourishment.

The quantities of contaminants contained in dredged material deposited in the marine environment are considerable, and further details on these inputs to the North Sea are given in Chapter 3. However, part of the trace metal content is of natural origin, and many operations simply relocate the materials rather than constituting fresh input to the environment. The Oslo Commission has adopted and keeps under review 'Guidelines for the Management of Dredged Material' with the aim of reducing any detrimental environmental impact.

Nature conservation

The North Sea and its adjoining coastal regions contain some of the richest wildlife habitats in the world. Many of these areas such as the Wadden Sea receive wide-ranging protection as conservation sites of national or international importance. Examples of the major habitat types are given in Table 1·8. A high proportion of the 5600 biotopes of major conservation importance reported to the European Community's Coordination of Information on the Environment (CORINE) programme are coastal sites (in some countries up to 40% of the sites), and the

Table 1·8. Examples of important habitats and their conservation significance. Geographical locations are shown in Figure 1·1.

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

great majority of them are covered by statutory protection.

Open waters of the North Sea support important populations of marine birds, both offshore species such as petrels, gulls, auks, and gannets, and inshore species such as ducks, divers, cormorants, and terns. Many of these birds spend most of their time feeding at sea and are vulnerable to surface pollutants such as oil. Vulnerability maps for North Sea seabird species have recently been updated in a collaborative international project for the North Sea Task Force (Figure 4·10).

About 40% of the world population of grey seals are found in the North Sea, together with about 10% of harbour seals as well as significant populations of small cetaceans and large fish such as sharks and rays. Many of the small cetacean species are protected from intentional killing, taking, or injury, while a range of other conservation measures are in hand to minimize impacts of, e.g., fishing and pollution. In response to the threats facing small cetaceans, a Memorandum of Understanding on Small Cetaceans was signed at the Third International Conference on the Protection of the North Sea held in The Hague in 1990. In 1992, a full 'Agreement on Small Cetaceans in the North Sea and the Baltic' was opened for signature under the Bonn Convention on Migratory Species. This new agreement will further promote collaborative research and conservation measures.

Archaeological sites

The floor of the North Sea is a submerged land surface which, in earlier times, served to unite human populations along present-day margins. Sea-level changes and land-mass movements have helped to preserve the remains of a number of ancient settlements on the bottom of the sea. The seabed has also received a scatter of shipwrecks of all periods. Archaeological remains on the seabed have special value due to the level of preservation found in anaerobic bottom sediments compared with those on land. Some sites are protected, but there has been no systematic attempt to plot the position and catalogue the sub-sea cultural remains in the North Sea. Seabed remains and shipwrecks are subject to unregulated disturbances and destruction by mineral extraction, navigational dredging, pipe laying, and pollution. A wide range of procedures for protecting marine archaeological artefacts exists in countries bordering the North Sea, but in most cases such procedures have not been enacted for specific sites.

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C H A P T E R

2

Physical oceanography

2.1.

Introduction

This chapter reviews the physical processes that have a direct influence on the ecology of the North Sea. Knowledge of these processes is required in order to link inputs to resulting concentrations, distinguish between natural variability and man's impact, and predict the effects of climatic and other long-term changes.

The Report of the Oceanography Subgroup to the Second International Conference on the Protection of the North Sea in 1987 provided a good description of the physical oceanography of the North Sea. Recognizing the basic information contained in that report, the present chapter considers the subsequent advances in scientific understanding of the North Sea. Interannual variability, especially when linked to changes in climate patterns, is a fundamental aspect of the physical processes of the North Sea. Since this variability has such a strong influence on North Sea ecology, special attention is given to it and the results of the most recent observations are presented here.

At the time of the completion of the 1987 *QSR*, oceanographers and modellers were still relying on the results of the international expedition JONSDAP '76 (Joint North Sea Data Acquisition Programme) to provide a framework for the description of North Sea oceanography. In the meantime, a number of new investigations have provided greater knowledge of the physical oceanography of the North Sea. In addition, closer collaboration among modellers during the past few years is leading to a more systematic approach to the development of physical, chemical, and sediment transport models of the North Sea. Recent developments in instrumentation, especially for measuring currents, such as the Acoustic Doppler Current Profiler, are providing new possibilities for furthering the understanding of these basic processes. Remote sensing has yet to be fully exploited as a monitoring tool in the North Sea because of the limitations imposed by the relatively persistent cloud cover over the area and the difficulty of 'calibrating' images. In future, it is expected that remote sensing, in combination with *in situ* measurements and modelling, will contribute significantly to improving our understanding of North Sea systems. Moreover, various initiatives of the European Economic Community within the framework of its Marine Science and Technology (MAST) programme now offer interesting prospects for international cooperation in the field of oceanography.

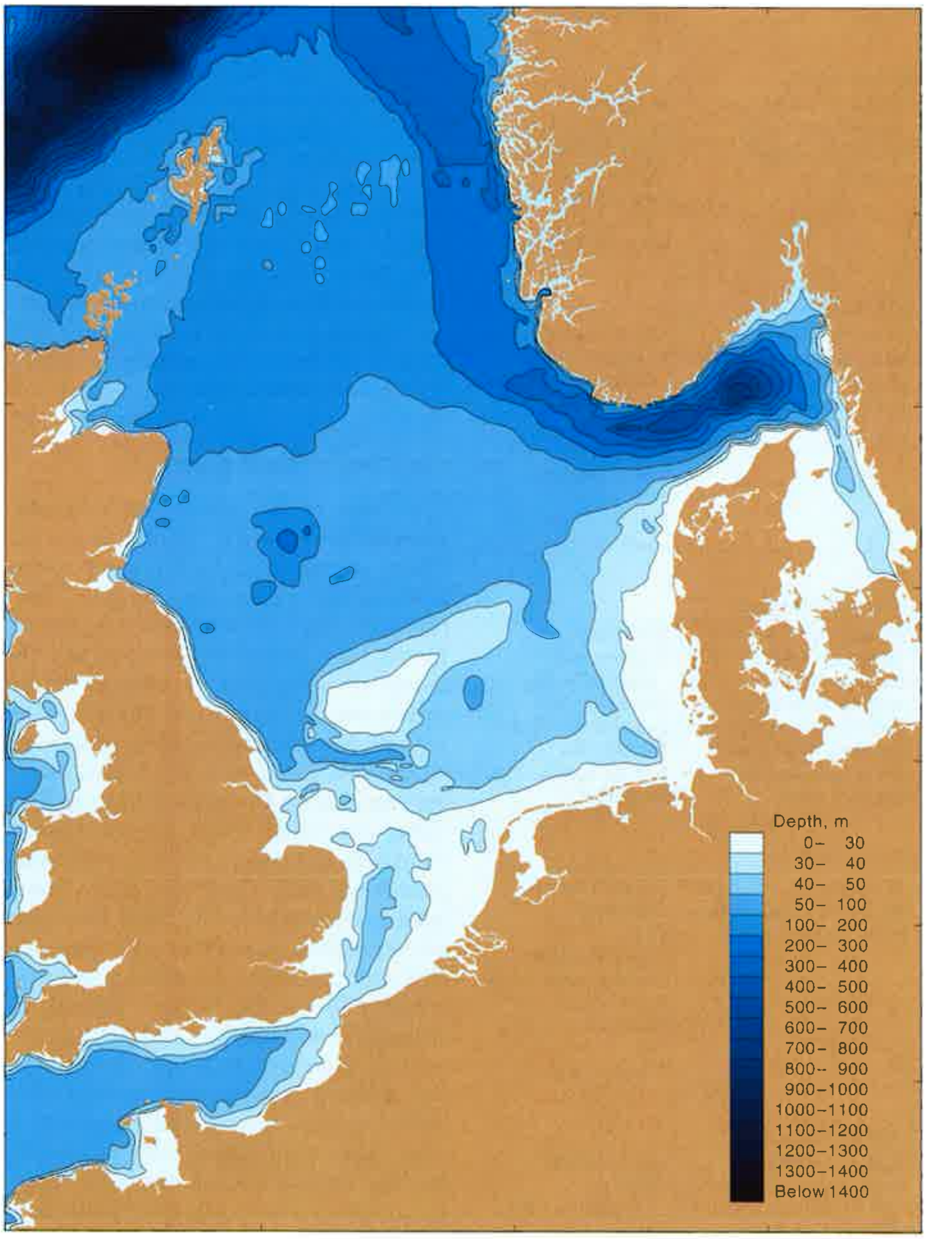


Figure 2·1. Bathymetry of the North Sea. Details of fjords not shown.

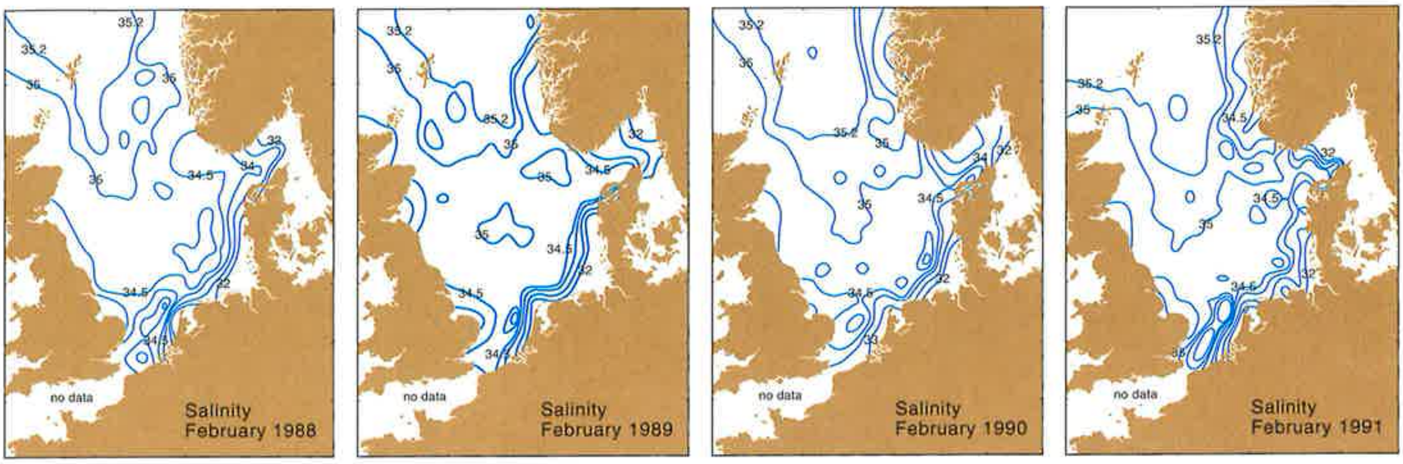


Figure 2·2. Surface salinities in the North Sea, 1988–1991. Source of data: ICES Oceanographic Data Centre.

From 1985 to 1992, the North Sea experienced climatic conditions that were exceptional for this century, and their effect on the physical environment of the North Sea is considered here. The winters in particular were characterized by marked changes, especially over the shallower southern North Sea, where a sequence of very cold winters was followed by exceptionally mild winters from 1988 to 1992. At the same time, notable dryness prevailed over southern England and the neighbouring continent. This dryness, along with the influence of high salinity Atlantic water, may have contributed to the record-high salinity levels in the North Sea and the Channel in the early 1990s. A continuing increase in storminess also occurred during this period, and there has been a 30% increase in wind speed at certain locations in the northern North Sea since the 1960s. This has not, however, been reflected in an increase in either the frequency or the intensity of North Sea storm surges, an observation which illustrates the need for caution in hypothesizing the consequences of at least one aspect of climatic change on the North Sea.

2.2.

Bottom topography

Figure 2·1 shows contours of water depths extracted from navigation charts. Such charts often accentuate minimum depths for safety purposes and are not completely accurate. The depths in these charts cannot be used in numerical models without correction.

Bottom topography is important in relation to circulation and vertical mixing. Flows tend to be concentrated in areas characterized by the steepest slopes, with the current flowing along the contours. The rectangular basin of the North Sea is shallow (30–200 m), with a shelving topography north to south and a deep trough (ca. 700 m depth), the Norwegian Trench, on its northeast margin. The Channel deepens gradually from 30 m in the Strait of Dover to about 100 m in the western part. The width of the Skagerrak and Kattegat region is approximately 100 km and the maximum depths are 700 m and 100 m, respectively.

2.3.

Physical oceanography

Structural features

Water mass characteristics

In the shallow North Sea, the water body originates from North Atlantic water and freshwater run-off in different admixtures. The salinity and temperature characteristics of different regions are strongly influenced by heat exchange with the atmosphere and local freshwater supply.

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 summarized in Table 2·1.

Physical parameters: salinity/temperature/light transmission

In the open parts of the North Sea, seasonal changes in sea surface salinity are comparatively small; in coastal waters beyond estuaries, salinity ranges from 33 to 35. As a result of the interannual and interdecadal changes within the North Atlantic current system and the intensity of vertical wind mixing, the salinity of the North Sea shows significant variability (Figure 2·2). Salinities were comparatively low in the late 1970s. They were very high, however, between 1989 and 1991 and comparatively high in the 1920s and at the end of the 1960s. The high salinities were caused mainly by a combination of reduced run-off and increased influence of Atlantic water on the North Sea in conjunction with climate-related changes in rainfall.

Table 2·1. Typical values for salinity and temperature of water masses in the North Sea.

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

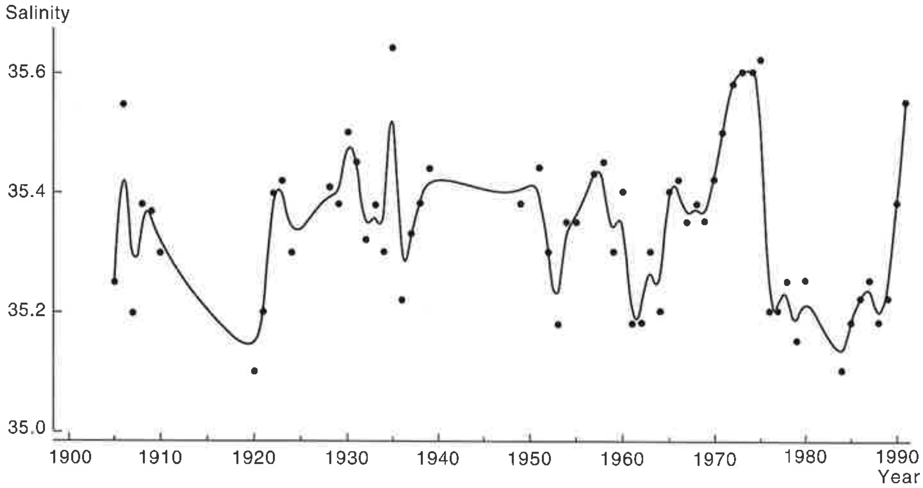


Figure 2·3. Trends in maximum salinity in the southern North Sea (52–54°N 2–4°E), 1905–1991. Source of data: ICES Oceanographic Data Centre.

Stratification

Most areas of the North Sea are vertically well mixed in winter months. In late spring as solar heat input increases, a thermocline (a pronounced vertical temperature gradient) is established over large areas of the North Sea, separating the lower from the upper layer. Thermal expansion of the surface layer reduces its density, and self-stabilizing stratification develops. The strength of the thermocline depends on the heat input and the turbulence generated by the tides and the wind. The depth of the thermocline increases from May to September and differs regionally, typically 50 m in the northern North Sea and 20 m in the western Channel. In

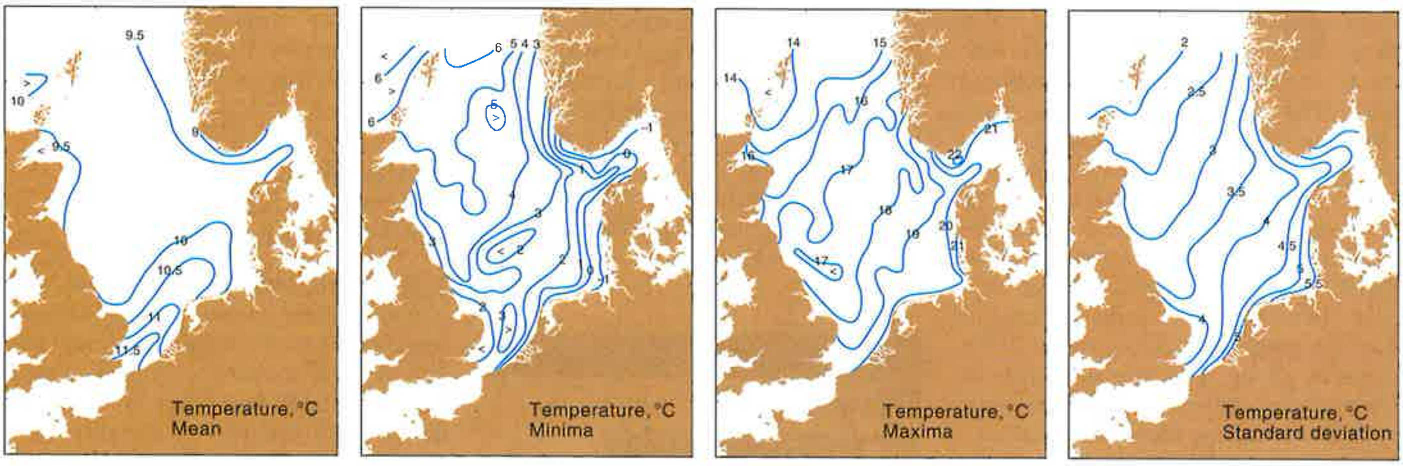


Figure 2·4. Sea surface temperatures of the North Sea, 1981–1990. Source: Becker and Wegner (1993).
Figures are based on data at grid points (20-mile grid) of the SST-program package of the German Federal Maritime and Hydrographic Agency.

Figure 2·3 shows the envelope of maximum salinities recorded in the southern North Sea during this century.

Sea surface temperatures of the North Sea show a strong yearly cycle, ranging from 7 to 15°C at the northern entrances and from 6 to 18°C in the Channel, with an even stronger cycle in the coastal margin, about 0 to 21°C in the shallow Wadden Sea and inner German Bight and in the Kattegat/Skagerrak region. Figure 2·4 is based on weekly digitized surface temperature maps of the North Sea, which have been produced since 1968. Sea surface temperature anomalies (i.e., differences from the mean) in the North Sea area normally range from about – 4°C to + 4°C.

Light transmission in the water column is mainly restricted by the suspended matter content and the amount of plankton present. The spatial and temporal variability of the light transmission is therefore great. Figure 2·5 and Figure 2·17 illustrate the high turbidity associated with river outflow, high plankton concentrations, and/or resuspension of bottom sediments.

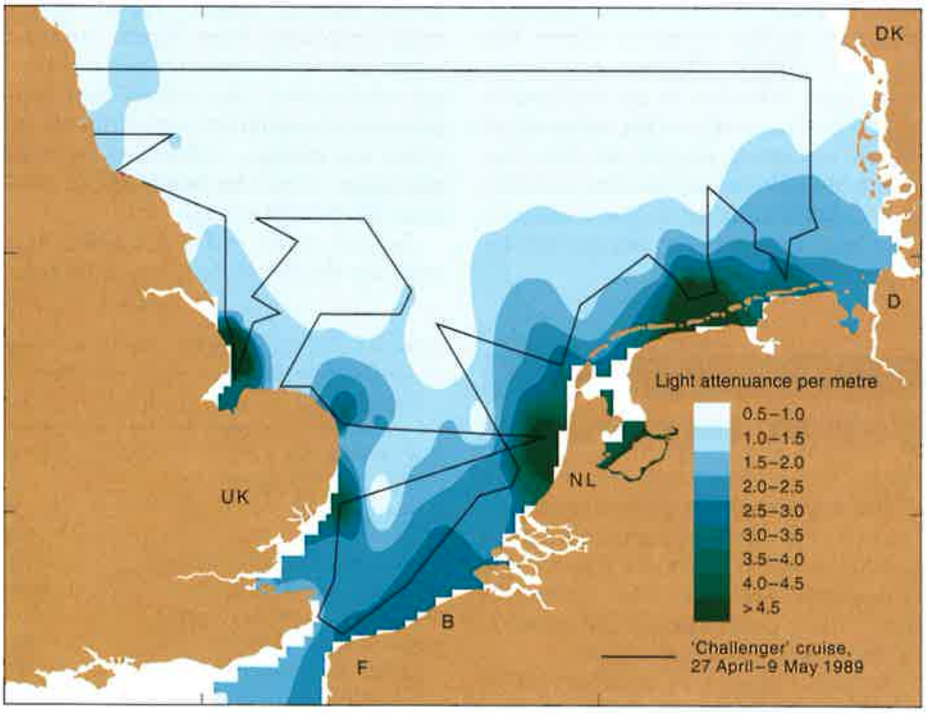


Figure 2·5. Light attenuance in the southern North Sea. Attenuance is directly proportional to suspended sediment concentration in sea water. Observations from (25 cm) on-board transmissometer from pumped samples during NERC North Sea Project cruise, April/May 1989. (Attenuance = –4 log Tr, Tr = fractional transmittance). Source: United Kingdom North Sea Project. Cruise of RV 'Challenger' (51/89: 27/04/89 to 09/05/89).

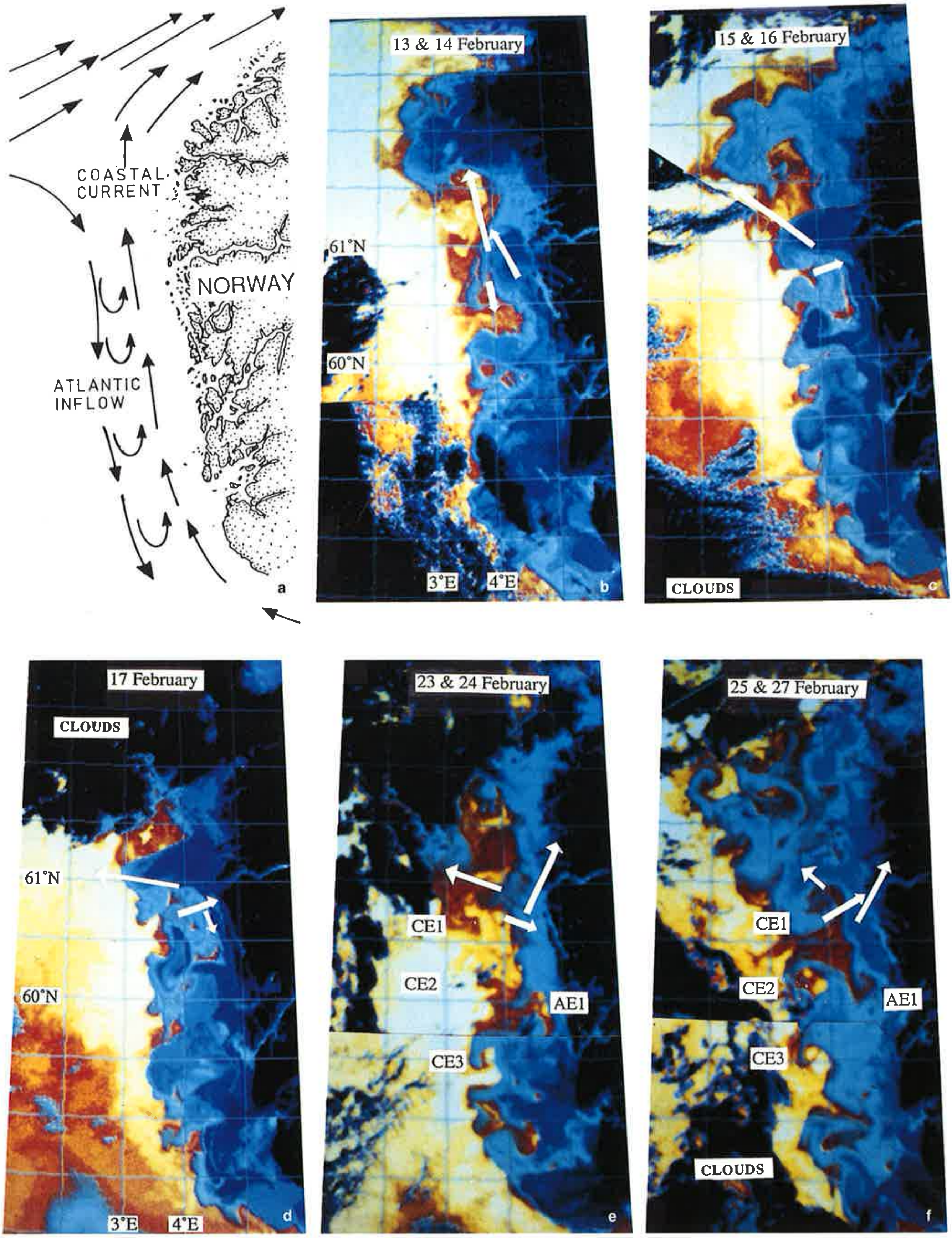


Figure 2·6. An example of circulation patterns and fronts in the northern North Sea.
Sequence of NOAA satellite infrared images obtained in February 1986. Source: Johannessen *et al.* (1989).
Yellow represents Atlantic water with a temperature of more than 7°C.
Dark blue represents coastal water with a temperature of less than 3°C.
Clouds appear as black areas over the ocean.
White arrows represent daily mean current vectors at 25 m or 50 m from three moorings.

autumn the increasing number and severity of storms, as well as seasonal cooling at the surface, destroy the thermocline and mix the surface and bottom layers. Some areas, particularly the Skagerrak, the Kattegat, the Norwegian west coast, and those off the large continental rivers, are permanently stratified because of freshwater run-off. In stratified waters, the vertical exchange of water between surface and bottom is significantly decreased. The shallow parts of the southern North Sea and the Channel remain well mixed throughout the year owing to strong tidal action.

Fronts

Fronts or frontal zones mark the boundaries between water masses and are a common feature of the North Sea. Satellite images (Figure 2·6) clearly illustrate discontinuities in surface properties. Fronts are important because they may restrict horizontal dispersion and because there is enhanced biological activity in these regions.

The separation area between well-mixed and stratified zones is often very narrow and results in the occurrence of thermal fronts (Figure 2·7). Meanders and eddies often form along fronts; such features can be simulated by numerical models and may be associated with strong current shears. Frontal zones are characterized by increased variability in water properties. In some areas, such as the Skagerrak and German Bight, strong upwelling events occur which also generate fronts.

Figure 2·8. Schematic diagram of general circulation in the North Sea. The width of arrows is indicative of the magnitude of volume transport. Source: after Turrell *et al.* (1992).

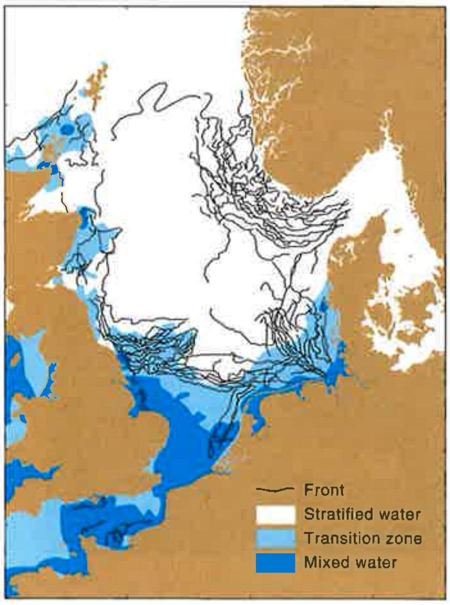


Figure 2·7. Transition zones between mixed and stratified water in the North Sea. Thermal fronts are deduced from satellite (IR) images; transition zones are calculated from the stratification parameter. Source: Becker (1990).

In many near-shore regions of the North Sea, strong tidal currents are oriented parallel to the coast. In areas such as the Rhine outflow, for example, river water spreads along the coastline. This water overlies the denser, more saline sea water, and a pattern of estuarine circulation is established perpendicular to the coast, which restricts mixing. 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 tidal currents to deviate from this longshore alignment.

Circulation and waves

A schematic representation of the general circulation in the North Sea is given in Figure 2·8. The importance of bottom topography (Figure 2·1) in steering this general circulation is evident during periods of weak winds. In summer, the surface manifestation of topographic steering is therefore less apparent because the upper layer is often decoupled from the lower layer, which is still subject to topographic steering. In some cases, residual currents may even be reversed for a period of time.

The residual flow in the Channel is to a large extent steered by the wind and tide. On average, this flow is from west to east, feeding a relatively narrow and saline core of Atlantic water through the Strait of Dover. The mean transport eastwards into the North Sea

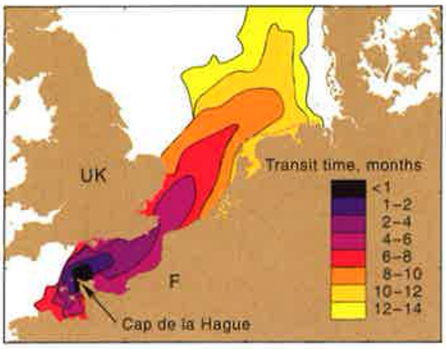


Figure 2·9. Dispersion of nuclear industry wastes in the Channel and the North Sea. Transit time (derived from radionuclide concentrations) for dissolved chemicals released at Cap de la Hague. Source: Breton *et al.* (1992).

is confirmed by the evidence seen in the dispersion of radionuclides discharged by the Cap de la Hague nuclear reprocessing plant (Figure 2·9).

Most of the North Sea water flows through the Skagerrak before leaving via the Norwegian Coastal Current. On short time scales (days to weeks), clear shifts take place between the different water masses entering the Skagerrak (Box 2·1). 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 rivers. Stronger inflows to the Kattegat occur in pulses, mainly during winter.

In the centre of the Skagerrak, water has a long residence time. Since most of the water of the North Sea passes (sometimes slowly) through this area, significant sedimentation occurs. Cores of accumulated sediments may give the best indication of the general historical trends in North Sea water quality.

Inputs of Baltic water and fresh water from Scandinavian rivers are important for maintaining the Norwegian Coastal Current and creating a stable surface layer in the entire Kattegat, most of the Skagerrak, and large parts of the northern North Sea. Since the surface water (depth 10 to 40 m) is stable, which is especially important for primary production, it can be moved by the wind with relative ease. Summer heating has a similar stabilizing effect (decoupling the surface and sub-surface water) over much of the North Sea, with the exception of the coastal regions and the tidally mixed waters in the southern part and the Channel.

Box 2·1. *The major inflows and outflows of the North Sea*

Most of the inflows to the North Sea converge in the Skagerrak. All of these flows, which combine to a cumulative transport of about 10^6 m^3/s as they enter the Skagerrak, are modified and/or dominated by wind effects.

The major flow consists of Atlantic water that follows the 200 m depth contour to the north of the Shetland Islands before passing southwards along the western edge of the Norwegian Trench. It has a typical transport of 10^6 m^3/s, about half of which enters the Skagerrak. Occasionally some of this water may pass southwards into the northern North Sea close to the eastern border of the Shetland Islands.

A flow of somewhat smaller transport (0.3×10^6 m^3/s) follows the 100 m contour and enters the northern North Sea between the Shetland and Orkney Islands as the Fair Isle Current. This flow is an admixture of coastal and Atlantic water that crosses the northern North Sea along the 100 m contour in a relatively narrow band as the Dooley Current before entering the Skagerrak.

In the southern North Sea, Atlantic water enters through the Strait of Dover from the Channel with a mean transport of 0.1×10^6 m^3/s. On occasion this flow can be suppressed and even reversed by winds. It moves erratically towards the Skagerrak, as does the water lying adjacent to the continental coast that is of low salinity due to the effect of the large rivers which flow into this region. The flow continues north as the Jutland coastal current and follows the Danish west coast towards the Skagerrak under the effect of prevailing winds.

The North Sea has only one outflow. It commences in the Skagerrak and is formed from all the above inflows and from water originating in the Baltic Sea and from Norwegian coastal run-off. This current, known as the Norwegian Coastal Current, has a transport of approximately 10^6 m^3/s as it leaves the North Sea. This balances the different inputs of water to the North Sea.

Observations and models demonstrate that the above circulation pattern is enhanced by southwesterly winds. Thus the circulation is normally stronger in winter than in summer.

Volume transport and water balance

The estimation of mean water transports in the North Sea is hampered by the large variability owing to frequent changes in wind velocity and seasonal changes in the density distribution (density field) as well as by the fact that this residual dynamic process is much less influential than the tides and storm surges that dominate in the North Sea. Climatic variability also causes very large interannual variations in water transports. Numerical models have been used to cope with this large spatial and temporal variability (Prandle, 1984).

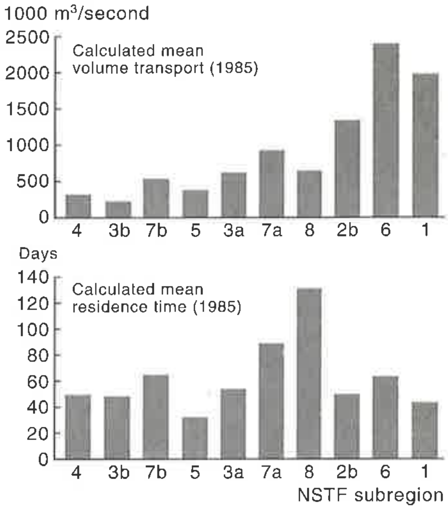


Figure 2·10. Hydrographic balance in the North Sea. Yearly mean estimates of the volume transports through NSTF subregions and associated residence times derived from the three-dimensional Norwegian Ecological Model system (NORWECOM). Source: Skogen (1993).

Figure 2·10 shows mean estimates of the volume transports and the associated residence times of the water transported through most of the NSTF subregions in 1985. Although the general directions of the residual flows are relatively well known, the volume transports and residence times are difficult to estimate with precision. Estimates of residence times based on observations and simple calculations compared with those based on models are shown in Table 2·2.

Models provide only an approximate simulation of real conditions and, in some cases, the discrepancies between the different estimates are relatively large for the following reasons: 1) runs were done for one year only (1985) or with climatic wind forcing; 2) the effect of the density field was included in some cases, but not in others; and 3) there was a resolution of the vertical structures of the flow in some cases, but a vertically integrated

Table 2·2. Comparison of different estimates of yearly mean residence times (days) for NSTF subregions.

NSTF subregion	ICES estimates 1983*	Turrell estimates**	NORWECOM (1985) estimates***	Prandle model†	Davies model‡	Hamburg SSCM¶
1	142	95	43	177	219	65
2b	109	87	50	156	110	90
3a	–	–	54	–	–	85
3b	464	–	48	–	–	110
4	73	–	50	78	55	80
5	73	–	32	86	37	70
6	76	70	63	155	146	65
7a	–	–	89	192	110	160
7b	547	–	65	83	73	–
8	–	–	131	–	–	–
9	–	–	–	295	–	–
10	< 17	–	–	–	–	–

*ICES (1983). ** Turrell (1992). ***Skogen (1993).
†Prandle (1984). ‡Davies (1982).
¶Shelf Sea Circulation Model. 1987. Institut für Meereskunde, Hamburg, Germany.

approach was used in others. It should also be noted that in some regions, the residence times in deep water may be much longer than in near-surface water. For example, in the Skagerrak, the residence time is of the order of years for deep water and of months for surface water. This clearly indicates that these estimates must be used with care.

Recent modelling/observation studies of caesium-137 discharges from Sellafield and atmospheric inputs resulting from the Chernobyl accident indicate flushing time estimates of approximately 500 days for the North Sea and 4.5 years for the entire northwestern European shelf seas (to 12°W and 62°N). Using antimony-125 and caesium-137 as tracers, transport times from Cap de la Hague were estimated to be of the order of 2 to 4 months to the Strait of Dover and 6 to 8 months to the western German Bight. These values are consistent with the upper values given in Table 2·2. While the values are 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 where the localized circulation (e.g., coastal trapping) close to a specific contaminant source may be crucial. For short-term (of the order of days) phenomena, such as plankton blooms, peak concentrations may be more sensitive to vertical exchange rates and relatively independent of the horizontal circulation (Prandle, 1990).

Tides

Tides in the North Sea result from gravitational forces of the moon and sun acting over 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).

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

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, owing to enhanced vertical mixing where such waves break as well as to the oscillatory movement of biota into the euphotic zone via the often large vertical displacements involved.

Tidal heights are greatly amplified in the bays along the French coast of the Channel. Estuaries in these regions are characterized by vast intertidal zones of both mud and sand, where highly mobile sediments tend to block river mouths.

In certain cases the frontal region between coastal and offshore waters is much reduced during neap tides relative to spring tides. Thus the exchange of suspended particulate matter (SPM) between coastal and offshore waters is reduced during spring tides, and SPM remains in coastal waters. For example, riverine waters and the associated SPM remain close to the French coast, move slowly northwards, and enter the Southern Bight of the North Sea through the Strait of Dover (Dupont *et al.*, 1991).

Box 2·2. *Fjords*

Fjords are often seen as a special type of estuary. A characteristic feature of Norwegian coastlines, a typical fjord has a sill at the mouth and a river at the head and may have water masses split into three depth zones. Freshwater run-off results in the formation of a brackish surface layer usually less than 10 m deep. During its flow seaward, this brackish water is gradually mixed with the underlying sea water and may be five to ten times greater than the freshwater input by the time it reaches the mouth of the fjord. In consequence an inflowing compensating current is established to make up for the loss of sea water from the fjord. Intermediate water occupies the zone between the brackish water and the sill. Water exchange in this layer is mainly governed by seasonal and short-term variations in coastal waters.

The density of the water in the basin, below the intermediate layer, gradually decreases with time unless renewal takes place. In some fjords there is an annual renewal; in others it may take up to ten years before the density of the basin water is sufficiently reduced and renewal occurs. However, unusually persistent wind conditions that cause strong upwelling on the coast can occasionally lead to renewal of basin water, sometimes with oxygen-depleted water upwelled to the surface.

At times the outflow from fjords can be very pronounced. In southern Norway this can often be seen in satellite images where the fjord water plumes can be traced far offshore during periods of northerly winds. The transport of nutrients and contaminants from the fjords to the North Sea is strongly dependent on their residual concentrations in the fjord water (in relation to primary production and sinking rates), which are in turn strongly related to the depth of the region of deposition as described above.

Estuaries and fjords

In estuaries and fjords, the surface outflows of brackish and less dense water originating from rivers entrain (draw in) salt water from below. The entrained water is replenished by a compensatory landward flow of salt water below the brackish layer (Box 2·2).

Storm surges

During severe storms, storm surges can occur in the North Sea. These sometimes cause extremely high water levels (Figure 2·11), 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.

Waves

Extensive measurements have been made to estimate the wave climate of the North Sea (Figure 2·12); this is of interest for, among other things, offshore platform design and shipping. Wave-spectrum models are also operated routinely in conjunction with atmospheric forecasting models. The wave climate of the North Sea has changed in recent years, with a tendency towards increasing wave height. 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 variability in contaminant concentrations. It is also important to understand the processes of wave–current interaction that can produce abnormal waves, which are potentially dangerous to, for example, shipping and offshore structures. In recent years, extreme-wave analysis for specific locations has also been relevant to site selection for fish farms.

Gyres/eddies

Satellite images of the sea surface invariably indicate numerous circular patterns of movement on a range of scales, known as gyres or eddies. Infrared satellite images in particular (Figure 2·6) show that eddies, which are probably an important cause of the generally known patchiness of biota and biological processes, are a common feature throughout the North Sea.

Gyres may be transient, generated along frontal boundaries, or stationary,

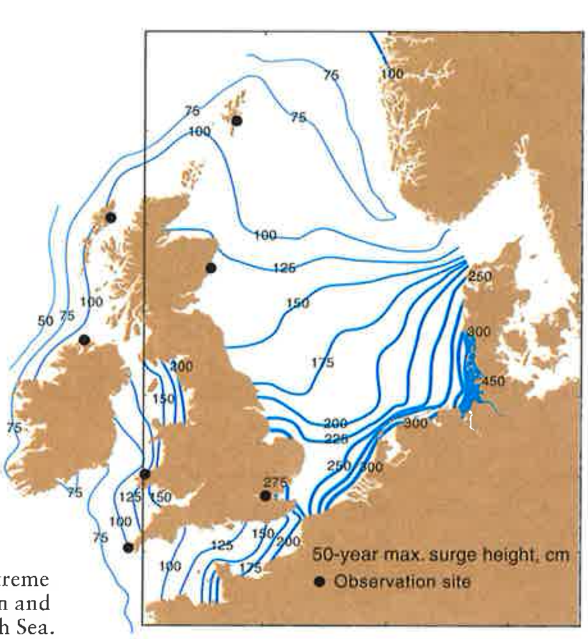


Figure 2·11. Maximum probable height of a surge in a 50-year period in the North Sea, based on models and observations at indicated sites. Source: Flather (1987).

Figure 2·12. Estimated 50-year extreme maximum wave height: distribution and associated wave period in the North Sea. Source: Department of Energy (UK) (1989).

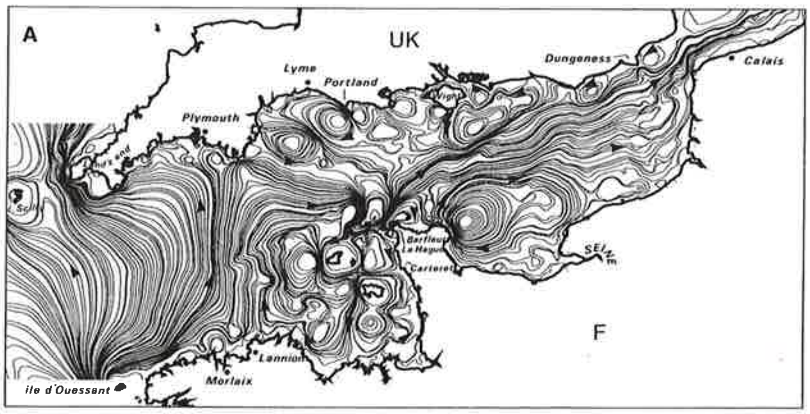
generated by topographical features. Small gyres have been observed along the Flamborough Front, located off Flamborough Head on the east coast of England. A much larger eddy generated by topography may be found to the north of the Dooley Current. More transient but very energetic eddies (typically 50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

Models have also revealed complex patterns of gyres in the Channel (Figure 2·13A). Abrupt changes in coastal topography may cause the longshore tidal flow to separate from the coast. Gyres in the residual flow may then result, especially where such separation produces differing flow speed and direction between the ebb and flood tides (Figure 2·13B). Recent developments in observational methods, in particular high-frequency radar, have shown that such features exist in almost all coastal regions, although with residual current speeds generally much slower than those indicated above.

Bottom water movement

In the tidally well-mixed areas of the western and southern regions of the North Sea, large-scale movements are generally independent of depth 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 (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, except in areas adjacent to bottom slopes where much of the water circulation is trapped; it is, however, usually very temporary as convection and mixing processes in autumn cause a rapid renewal of these waters.

The slowest bottom water movements occur in central parts of the Skagerrak where depths exceed 700 m, i.e., the deepest part of the North Sea. Here waters are normally replaced at a much slower rate (2–3 years), but rapid changes can occur when bottom water cascades into the Norwegian Trench in winter (Ljøen, 1981). The



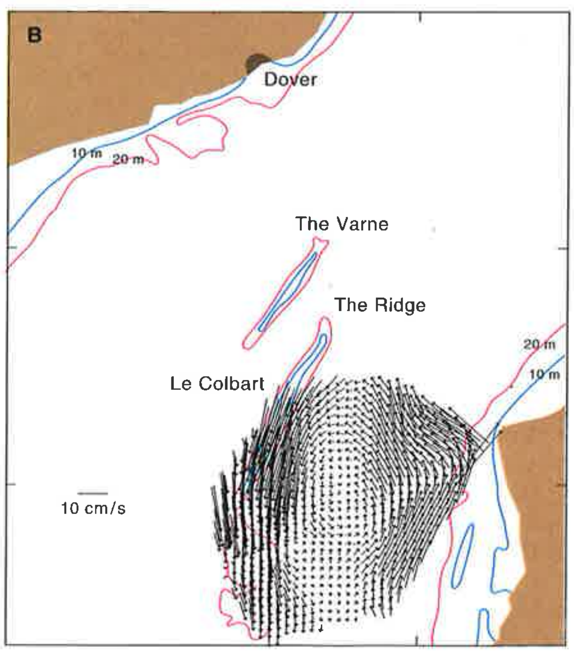


Figure 2·13. Gyres in the Channel.
A: Long-term trajectories due to the tide.
Source: Salomon and Breton (1991).
B: Residual surface current gyre in the eastern Channel at the Strait of Dover.

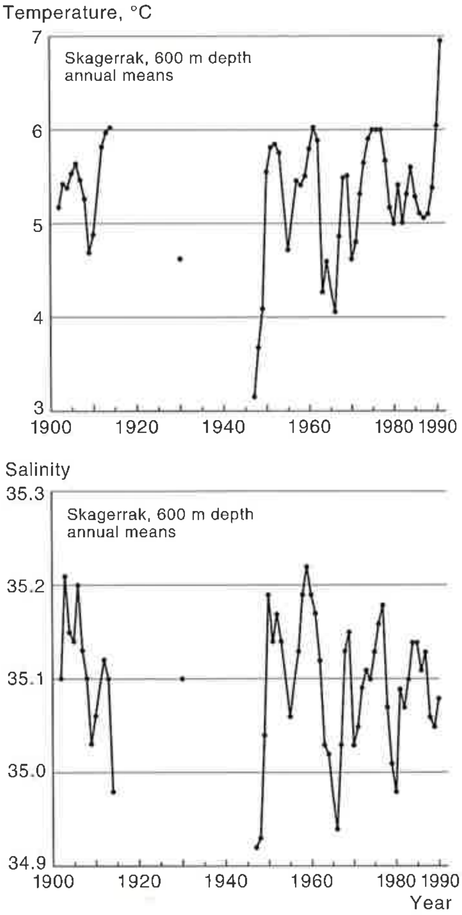


Figure 2·14. Annual mean temperature and salinity at 600 m depth in the Skagerrak. Source of data: ICES Oceanographic Data Centre.

time series of temperature and salinity at 600 m depth in the Skagerrak from 1902 to 1914 and from 1947 to 1991 illustrate the magnitude of these changes (Figure 2·14).

Climatic differences

The main causes of long-term (season to 100 years) variability of the North Sea are fluctuations in: a) surface heat exchange, b) wind field, c) inflow of Atlantic water, and d) 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 to 3°C, which may be important for, e.g., Skagerrak bottom water renewal (Ljøen, 1981). The variable heat input that occurs during summer is important in relation to the surface temperature, but it is relatively less important in the deeper water since the stability created during heating effectively prevents vertical heat exchange. Climatic changes in the North Sea can often be discerned in the characteristics of bottom water masses (Svendsen, 1991); this is discussed in greater detail in the preceding section on bottom water movement.

It has been demonstrated by large amounts of hydrographic and meteorological data available for 1968–1990 that the winter cloud cover is important in determining the heat content of the northern North Sea. Large year-to-year variations in the inflow of Atlantic water are observed, but it seems that the causes for these in part lie outside the North Sea. The influence of Atlantic water is important for general circulation in the northern North Sea and the Skagerrak. Because Atlantic water is the main source of nutrients 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.

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), 1977–1979 and possibly 1942 were probably the coldest. The 1977–1979 cold period was associated with very low 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. Models are now being developed with the objective of predicting ocean climate by means of sophisticated circulation and heat exchange numerical simulations; the validity of such models will be demonstrated by the degree to which they can correctly simulate these extreme happenings.

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 showed a decrease of about 2°C. In the deeper waters, no such clear trends have been observed.

Figure 2·15 shows the monthly mean cubed wind speed from 6-hourly measurements at an island west of Norway (Utsira) since the 1950s. Very large variations have occurred in the wind field, and an increasing trend in the wind speed has been noted from the early 1960s until today, 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.

As a consequence of increasing concentrations of greenhouse gases in the atmosphere, temperatures are likely to increase. The resulting effect on radiation processes can be expected primarily to raise sea surface temperatures globally. However, the climate system, with its manifold components and positive and negative 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 northwestern Europe will be an area of less rapid warming than more continental regions. At present, there are no strong indications of rapid warming. Ocean circulation in the North Atlantic region is of primary importance for the Nordic climate. A rough interpretation of the output from a coupled model from the Max Planck Institute suggests that the Nordic area will be subject to an increase in surface temperature, an increase in precipitation (Scandinavia), and a decrease in Arctic ice volume. However, regional scenarios of coupled models remain uncertain. There have also been suggestions that an increase in storminess may be associated with the expected increase in temperature. There is now consider-

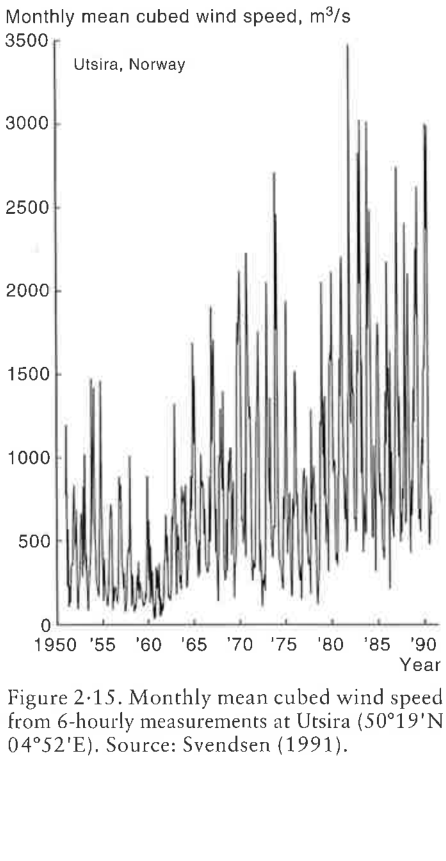


Figure 2·15. Monthly mean cubed wind speed from 6-hourly measurements at Utsira (50°19'N 04°52'E). Source: Svendsen (1991).

able speculation as to whether climate changes will take place over the next few decades and, if so, in what manner. There is no real method for predicting what effects climate change may have on the North Sea ecosystem, and it is therefore very important 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 be continued under the auspices of the relevant intergovernmental organizations and perhaps even expanded. 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.

The average rate of change of Mean Sea Level (MSL) over the last century, as determined from tide gauge data, is of the order of 1–2 mm per year at most stations, with weaker or even negative trends observed in Scotland and Sweden, and larger increases around the German Bight, in southeastern England, and at mid-Channel ports in England and France (Figure 2·16). The spatial pattern is similar to that determined from geological data averaged over several thousand years, indicating a tilt of the land mass.

Locally, extensive construction work and deepening of navigation channels to major ports may have a stronger 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.

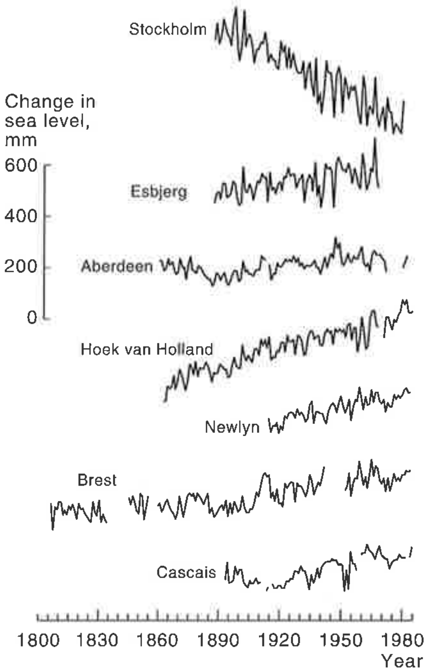


Figure 2·16. Representative long-term records of sea level along Northeast Atlantic and Baltic Sea coastlines.

Figure 2·17. Transport of solids and circulation patterns in the North Sea. Nimbus-7 satellite CZCS colour composite image obtained in March 1982, showing suspended matter distributions, and absorption by chlorophyll and dissolved organic matter. Source: Aiken (1989).

Transport of solids

Sediments: cohesive and non-cohesive

Fine sediments (< 63 µm in diameter) are important as the medium by which many adsorbed contaminants are carried from river to estuary, estuary to coastal zone, and thence to shelf sea/ocean. This physical transport may be as rapid as the transporting water or much slower with intermittent periods of settlement on the seabed. Not only do these sediments convey contaminants, they can also influence the biology of the coastal zone by their extinction of light, thereby severely limiting photosynthesis in deeper turbid waters. Over longer time scales, some (evolving) balance will be achieved between the changing bathymetry due to erosion and settlement of sediments and the subsequent modification of the forcing mechanisms (tides, waves, density gradients).

Sediment erosion and deposition

The settlement of contaminated sediments onto the seabed is an important sink that reduces the net (dissolved plus particulate) concentration of a contaminant in sea water. However, this sink can be a subsequent source releasing contaminants back into the sea water as a result of bottom stirring during storms or, more insidiously, as a slow but persistent leak of pore water back into the sea (with the chemical constituents possibly changed by biological activity). These seabed exchange processes may determine the longer term mean concentrations in sea water for many contaminants irrespective of future rates of inputs from other sources.

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. This causes the topography of the seabed to change, and contaminants adsorbed to settled particulate matter can be resuspended, transported, and deposited elsewhere (Figures 2·17 and 2·18).

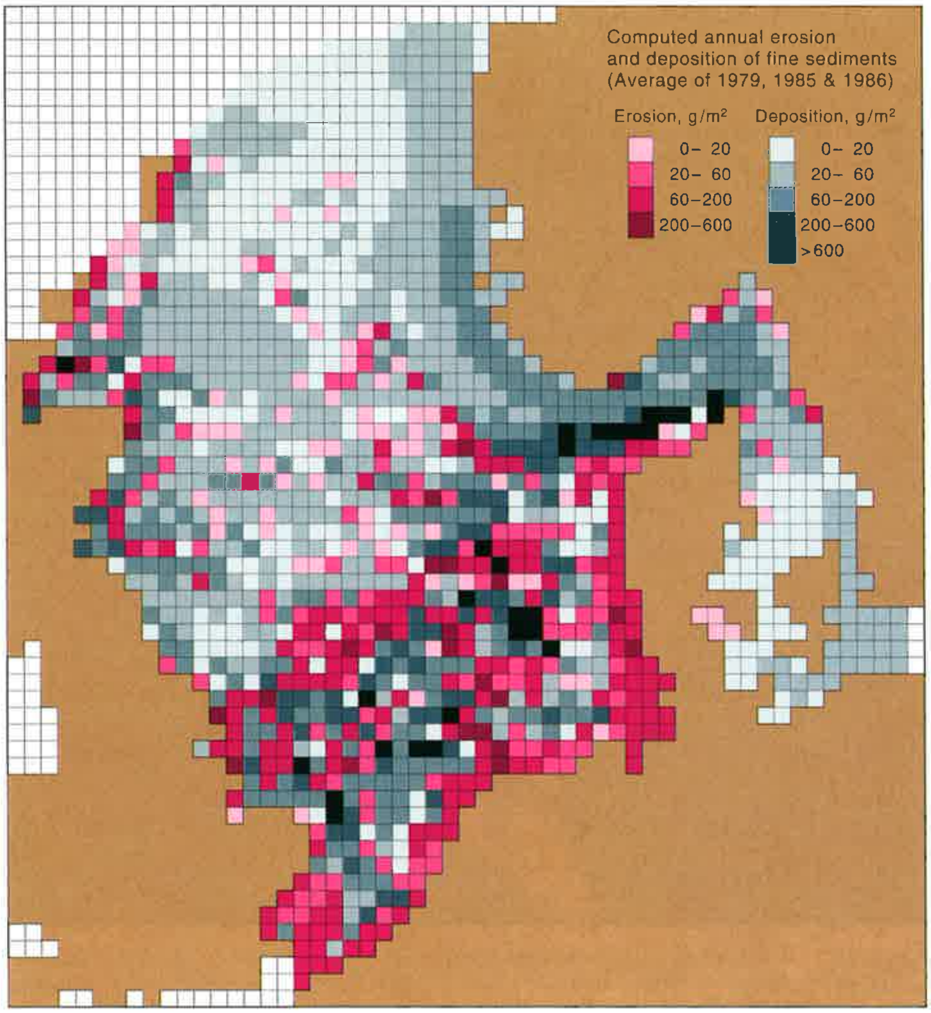


Figure 2·18. Erosion and deposition of sediments in the North Sea. Computed annual erosion and deposition of fine sediments (average of three years: 1979, 1985, 1986). Source: Pohlmann and Puls (1983).

Due to the nature of the material and the quite different time scales involved, the transport and sedimentation of suspended particulate matter (SPM) and the erosion of fine sediments are difficult to distinguish and to monitor. The development of coupled advanced numerical models has made it possible to simulate the SPM deposition and fine sediment erosion areas of the North Sea. The limitations of such models include rather coarse spatial resolution (20 km) and the omission of density differences within the water column from the conditions modelled. Averaged simulations for 1979, 1985, and 1986 are shown in Figure 2·18. The deposition rates determined by this model can be compared with observed sediment accumulation data. For the northern North Sea (Fladen Ground) and south of the Dogger Bank, the agreement between empirical and model results is satisfactory. For the Skagerrak, however, 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 northeastern sector.

Table 2·3. Supply, outflow, and deposition of suspended matter in the North Sea. Source: Eisma and Irion (1988).

	Amount 10^6 t/year
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	ca. 51.5–64
Outflow and deposition	
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 Channel	ca. 17
Dumped on land	2.7
Total	ca. 51.9–62.4

Table 2.3 gives details of the amounts of particulate material transported, as averaged over three years. Particulate matter originating from external sources (such as adjacent seas, rivers, dumping, cliff erosion) contributes to a yearly average of 23.7 million tonnes deposited in the North Sea. The sum of erosion and deposition of fine sediment particles is not quite zero because of temporal changes in the SPM mass in the North Sea water body.

Remote sensing and modelling

Remote sensing

In the late 1970s, sea surface temperature distributions obtained from American weather satellites clearly illustrated the existence of mesoscale phenomena such as fronts and eddies, and this stimulated increased research on these topics. Thermal infrared observations, although hindered by cloud cover, are the most widely used remote sensing tool.

Satellite observations by microwaves (all weather) giving estimates of sea level (limited accuracy) and wave height have been operating continuously – mainly by the United States – for many years. The launch (in 1991) of the European ERS1 satellite promises significant advances in estimates of these parameters, together with wind (speed and direction) and the length and direction (both surface and internal) of waves.

With respect to satellite monitoring of certain measures of water quality (chlorophyll and turbidity), the necessary optical sensors have not been available since the period 1979–1986 when the Coastal Zone Color Scanner (CZCS) was in operation. A similar sensor (Sea WiFS) is due to be launched on the Sea Star satellite during the spring of 1994. Later in the 1990s the European Space Agency, Japan, and China also plan to launch satellites containing similar sensors. The main limitations in the use of optical remote sensors are, of course, cloud cover and darkness, but there are also uncertainties as to the extent to which atmospheric conditions affect the signals. Data on colour, temperature, suspended matter, etc., obtained by remote sensing techniques relate only to the near-surface water layers. This compounds the difficulty of providing the strictly relevant surface truth data that are necessary if biological parameters are to be accurately related to optical spectral data.

Sensors from aircraft are widely used to measure the temperature and colour (related to suspended sediment/ biological concentrations) of the sea surface and to detect oil pollution. Shore-based high-frequency radar has been widely used to measure near-shore (up to 40 km from the coast) surface currents. New technical developments will extend this coverage and should also enable surface wave heights and direction to be determined.

Modelling

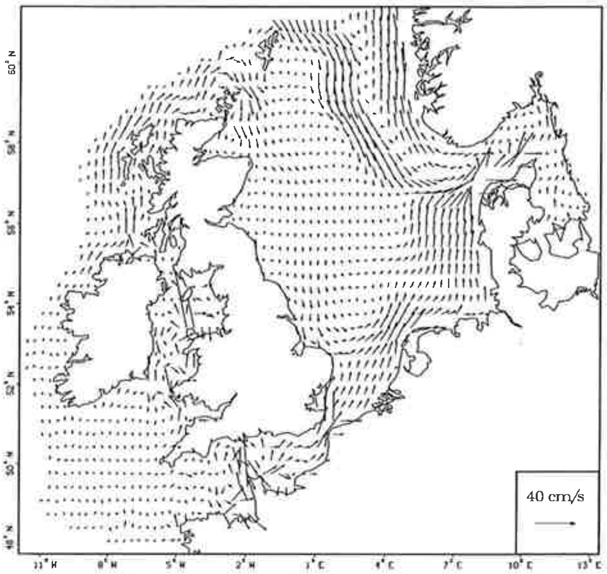
Considerable effort is now being expended on the development of models to simulate North Sea systems. These models can be either laboratory models, for example, rotating tanks incorporating realistic bottom topography, or numerical models. Numerical models are widely used for the simulation of many aspects of the North Sea ecosystem, and their current status is summarized below.

Since the 1970s two-dimensional (2-D) numerical models of the North Sea have been used primarily for tide and storm surge prediction. These models are of the diagnostic barotropic type and have proved useful in simulating the spread of caesium-137 from its source in the Irish Sea. The resulting predicted distributions of this tracer in the North Sea accord reasonably well with empirical observations.

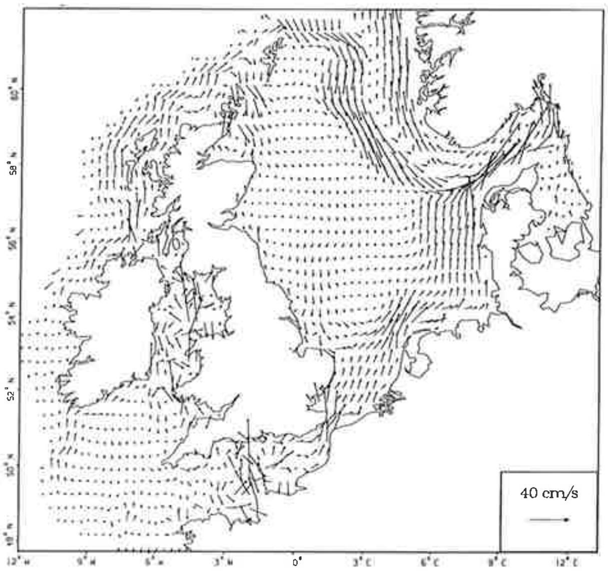
Increases in computing power during the 1980s have facilitated the development of models that are much more sophisticated than the earlier 2-D models. In particular, the development of 3-D circulation models that include atmospheric forcing, tides, density gradients, and heat and salt fluxes has progressed rapidly (Figure 2·19). These models could be developed further, for example, to drive high-resolution local area models designed to answer specific questions in sensitive areas.

Continued development of 3-D models will eventually lead to a more precise simulation of many complex features of the North Sea, such as the mixing processes over the seasonal cycle. The effects of density gradients on circulation can be incorporated directly into these models because of their capacity to simulate temperature and salinity distributions. The main features of a major front off the east coast of England, the Flamborough Front, have been well simulated, though the sharpness of the calculated density gradients may have been diminished somewhat as a result of smoothing during the numerical processing. Good progress is now being made in coupling these

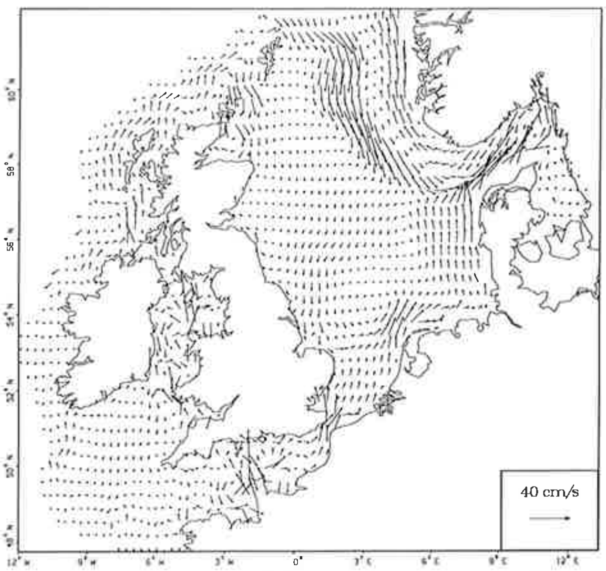
Figure 2·19. Velocity fields computed from a 3-D baroclinic model. Source: Delhez and Martin (1992).



Surface residual velocity field in typical summer conditions with the three main forcings (inflow–outflow, mesoscale Reynolds stresses, uniform wind stress).



Depth mean residual velocity field in typical summer conditions with the three main forcings (inflow–outflow, mesoscale Reynolds stresses, uniform wind stress).



Bottom residual velocity field in typical summer conditions with the three main forcings (inflow–outflow, mesoscale Reynolds stresses, uniform wind stress).

types of models with biological (e.g., eutrophication) and sediment models, which require good representations of vertical mixing rates.

Although progress is being made in most North Sea countries in the development of 3-D models, the rate of progress is restricted by a number of obstacles. The most serious of these include difficulties in assessing the comparability of models, and in validating them against reality. A promising start to this process was made at the NSTF Modelling Workshop (The Hague, 6–8 May 1992) where five different models were run, using a common data set when possible, to predict the effects of a 50% reduction in nutrient inputs on basic eutrophication variables. With some exceptions, the results of the different models were consistent in direction and relative size of effects. For the coastal region of the southern North Sea (NSTF Subregion 4), most of the models predicted a reduction of 16–24% in winter nutrient levels, with annual primary production decreasing by a similar amount. Careful interpretation of these results is needed, however, as some models do not simulate important processes involved in nutrient dynamics or physical features such as coastal fronts, which must have an influence on nutrient reduction scenarios. Reductions in cadmium and PCB concentrations were also evaluated in the workshop, but with less success because of difficulties in parameterizing the observed steep gradients to the grid scales of the models.

Validation of model results remains one of the most important issues that must be dealt with in the next few years. It is often tempting to side-step this issue, particularly as model results portrayed on a computer screen or in print-outs often provide a clearer picture than that offered by observations. The temptation is therefore to give model results a much higher status than they deserve at present. However, so long as temporal and spatial densities of oceanographic data remain inadequate for comparison with models, it will be difficult to overcome this situation. Every effort must be made to fill this shortfall in observations, and procedures should be developed to allow a comparison of model results with observations to be put into a clear statistical framework. As part of this objective, a protocol must be established for comparing different models in order to assist in the resolution of conflicting results. Both of these needs require the use of standardized data sets as a means of limiting the sources of conflict between models.

As a result of initiatives by the NSTF, the preparation of standardized data sets for North Sea bathymetry, temperature, and salinity is already under way, thereby allowing progress to be made in addressing these issues. However, there is a need for similar information on contaminant and nutrient inputs and concentrations. There is specifically a lack of data simultaneously observed in space and also in the form of time series that are on scales comparable to those used in models. The core of an ideal research/monitoring system would be a combined use of ships, models, and remote sensing, with a few moored buoys for measuring currents and sea level, at well-selected points, including the open Atlantic boundaries of the North Sea.

2.4. Anthropogenic modifications of coasts, sea bottoms, and physical hydrography

Coastline modifications

Human activity is responsible for at least two types of change that can alter the physical environment of the North Sea: alterations of river flow and alterations of the coastline. Freshwater runoff is altered when water is removed or diverted for industrial and domestic use and, particularly, for agricultural irrigation; in addition, flow rates and the time of maximum flow are affected by hydroelectric power schemes. At least locally these changes can drastically alter the seasonal cycle of the near-surface hydrographic structure and circulation, which may lead to changes in ice formation during the winter. More generally, changes in near-surface stability and circulation can affect species dominance and alter biological diversity.

Sea defence works for protection or land reclamation purposes are common features of the North Sea coastline, particularly around the more shallow Southern Bight. Until recently, coastal protection works have usually been in the form of hard structures designed to minimize erosion along the shore by dissipating wave energy or simply by holding back the waves and tides. It is now realized that such structures may starve adjacent areas of natural deposition material, leading to erosion elsewhere, and that they usually require expensive regular maintenance. The present tendency is to use soft engineering approaches, such as beach replenishment and salt marsh colonization, or to allow natural processes to take their course at a controlled rate. Both the former approach and more recent strategies will result in changes in coastal habitats, and in some cases, coastal circulation may also be altered.

Major land reclamation projects such as those along the Dutch coast, e.g., the Rotterdam harbour area and Slufter, and in the Tees Estuary, alter both current speeds and circulation patterns, as well as the more obvious alteration of coastlines and habitats.

The Dutch Delta Works (1970–1985), which restrict the main flow from branches of the Meuse and the Rhine, have had two major effects on the coastal zone: 1) the outflow is now generally limited to one 'jet-stream' from the Nieuwe Waterweg, almost without extensive brackish water zones; and 2) the Voordelta, an area of intertidal sand flats (sand banks), has been formed in front of the former tidal gullies, channels, and islands and constitutes a potential new habitat for benthos, birds, and mammals.

Industries

Oil and gas industry: platforms, rigs, and pipelines

Offshore platforms, drilling rigs, and pipelines installed by the oil and gas industry may influence the physical marine environment because they can affect waves and current velocity in their immediate vicinity. Platforms also play a role in changing the physical environment through the discharge of waste waters, round-the-clock artificial lighting, and the spread of particles/mud affecting the transparency of the water and local bottom sediments. All of these effects are essentially local.

Offshore engineering: man-made islands, and sand and gravel extraction

Most commercially workable deposits of sand and gravel occur in the shallower regions of the North Sea; they are usually relict deposits from earlier ice ages. The main concern when such deposits are exploited is the impact on fishing interests and coastal protection. Removing material from sand and gravel banks close to the shore can increase the potential for coastal erosion. Fishing interests are affected directly when fishing is excluded from areas where deposits are being worked, but they may also be affected indirectly if the seabed is altered either by total removal of the deposits or by the deposition of fine particles from washing or screening of the dredged deposits. The Code of Practice for the Commercial Extraction of Marine Sediments recommended by ICES advocates a ban on screening at sea, and the removal of only a proportion of the total depth of the deposits. Whether or not this Code of Practice is followed, damage to and alteration of the benthic fauna are inevitable, and the time needed for recolonization is not yet readily predictable. If the exploited deposit is in shallow water close to the coast, the wave energy reaching beach areas may be affected, resulting in coastal erosion.

Trawling

The impact of trawling on benthic species is discussed in detail in Chapter 5. Repeated passage of trawls increases the amount of suspended matter in the water column and thus affects light penetration and may contribute to eutrophication effects by reducing denitrification. Trawling may alter the seabed so that a relatively well-compacted cohesive sediment becomes one with a lighter structure that is much more readily eroded by storm action. Apart from the obvious consequences for biota, this may lead to alterations in both water depth and current flow.

Sea disposal: solid waste, including dredged material

In future, the main waste materials to be deposited at sea will be those dredged from the seabed either to maintain existing harbours or navigation channels or to create new ones. Both dredging operations and disposal of material removed lead to increased concentrations of suspended matter in the water column. Although this increase is usually a short-term one, light penetration is reduced and primary productivity in the area may be affected. Most harbour dredgings are contaminated to some extent by metals and organic substances that enter the water either directly from harbour operations or via discharges from other land-based activities and are adsorbed onto particulate material that settles with the sediments. When these sediments are disturbed by dredging operations, some of the contaminant load may be released, but even if it is not, it may impact the biota in the deposition zone. The extent to which adverse effects occur will depend on the dispersion characteristics of the disposal site. Certain types of dredged material may be used for beneficial purposes such as beach nourishment and salt-marsh preservation or as landfill.

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CHAPTER

3

Marine chemistry

3.1. Introduction

The 1987 *QSR* presented a considerable amount of information on contaminant concentrations in the North Sea, as well as noting problems with the comparability of data provided by different laboratories. For water and sediments the information contained in the *QSR* was largely qualitative, with the exception of that on caesium-137, nutrients, hydrocarbons, and hexachlorocyclohexane (HCH, including γ-HCH, the insecticide lindane) in sea water, and on hydrocarbons in sediments. It was not possible to obtain a comprehensive overview of trace metal concentrations in North Sea sediments since different extraction and leaching techniques were applied in different laboratories to different size fractions of sedimentary material. Because fine sediments generally exhibit higher concentrations of metals than coarser sediments, whether from natural or anthropogenic sources, the proportion of fine material is a critical factor in determining the total metal content of a sediment. Temporal trends can only be assessed in stable depositional areas, and studies conducted in one of them, the Oyster Ground, suggested that increased metal concentrations were related to an increase in industrial activities after 1880.

Inputs of contaminants to the North Sea from various sources were summarized in the 1987 *QSR*, with particular attention to nutrients, metals, oil, and radioactive substances. These included direct inputs, those via rivers or the atmosphere, and those arising from disposal and shipping operations or the exploitation of offshore oil and gas. Estimated input data provided by different countries were, however, difficult to compare, and all data were subject to considerable uncertainties. The main trend identified was an increase in hydrocarbon inputs from offshore installations over the period 1981–1985, 90% of which arose from the use of oil-based drilling fluids in both exploration and development drilling. In 1985 the discharge of oil from this source was estimated to be 25 760 tonnes. An update of this input information was presented in the 1990 *QSR*.

In this chapter, the spatial distributions of contaminants and nutrients in sea water, sediments, and biota are presented for the entire North Sea. When time series of measurements are adequate in terms of frequency of sampling and length of time, temporal trends are addressed. The quantities of contaminants entering the marine environment are given according to both their natural and anthropogenic origin. For a number of elevated concentrations due to human activity, the causes are discussed at the end of the chapter.

3.2. Distribution

In order to improve the spatial coverage and comparability of the data to be used in the 1993 *QSR*, a Monitoring Master Plan (MMP) was prepared (Box 3·1). This plan drew upon the experience of the International Council for the Exploration of the Sea (ICES) and the Joint Monitoring Group (JMG) of the Oslo and Paris Commissions (OSPARCOM) to specify particular requirements and set priorities in terms of data collection and quality control. The overall aim was to conduct surveys to establish the spatial distribution of contaminants throughout the NSTF area. It was envisaged that decisions based on the results obtained would define the areas where further monitoring should be carried out, either to elaborate the spatial detail in particular subregions or to establish temporal trends.

Sampling locations were selected and the work was divided according to which country had the most direct interest in the location concerned. A number of stations were designated as controls to be monitored by several countries.

The Monitoring Master Plan document included a list of mandatory and optional determinands (substances or parameters to be measured). Based on advice from ICES and the JMG, priority monitoring matrices were defined for each of these determinands. For most determinands, sediments were considered to be the most appropriate matrix for both spatial and temporal studies, and surveys of contaminants in sediments were therefore accorded high priority. Certain exceptions were

> Box 3·1. *The Monitoring Master Plan of the North Sea Task Force*
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> When it was formulated in 1989, the Monitoring Master Plan (MMP) targeted two main objectives: first, to provide the information necessary to assess the condition of the North Sea, and secondly, to provide a basis for future programmes that will permit temporal trends in physical, chemical, and biological parameters to be assessed.
>
> As a core programme to be used on an international scale, the MMP aims to coordinate both chemical and biological monitoring throughout the North Sea area. It incorporates some determinands (substances to be measured) for which relevant data of suitable quality were not already in existence in 1990 or which would not be surveyed by existing monitoring programmes. The mandatory list of determinands to be monitored under the MMP includes metals, trace organic compounds, nutrients, and related interpretation parameters (such as salinity or sediment grain size distribution). The concentrations and spatial distribution of contaminants were also measured in sediments, as well as in biota, and to a lesser extent in sea water. A voluntary list of items to be measured wherever possible includes additional chemicals and also biological parameters to be monitored in relation to eutrophication phenomena.
>
> Considerable research has been devoted to the development of biological effects monitoring in recent years, and several techniques were considered to be sufficiently well tested to permit their use. The techniques chosen for inclusion in the MMP include studies of benthos (invertebrates living on the seabed) in relation to contamination sources, fish diseases, induction of a detoxification enzyme (EROD) in flatfish liver, and a water quality assay using oyster embryos.
>
> Monitoring stations were selected in order to cover the open North Sea and the coastal areas where transects have been placed in front of the main estuaries.

recognized; for example, HCH is not accumulated in sediments and is best surveyed on the basis of water samples. Priority matrices were also set for the optional determinands. Because sea water is not regarded as the optimal monitoring matrix for most contaminants other than nutrients, most contaminants were monitored in sediments or biota. The main MMP survey work was conducted in 1990/1991, and the results were collated by ICES and assessed by specialist groups.

The data on spatial distributions of contaminants, which are referred to in the following sections (Box 3·2), are derived mainly from MMP surveys, but also include supplementary data from other international or national studies when they were provided in subregional assessment reports. Both the quantity of data and the coverage achieved represent a considerable advance over previous studies, and in some areas, such as off the Norwegian and English coasts, the coverage of contaminants in sediments is particularly good. However, despite the initial undertakings as to what was to be done and how, the data still suffer to some extent from a lack of comparability and insufficient information on quality assurance procedures. Some countries placed greater emphasis than others on the non-mandatory matrices and determinands or failed to follow other parts of the agreed protocol in full (e.g., analysing particular size fractions of the sediment rather than total sediment, or using a method of analysis different from that which had been agreed). Nevertheless, the data have generally permitted assessment on a holistic basis by expert groups, and where conclusions on differences in spatial distribution are presented, they can be regarded as being reasonably reliable.

Box 3·2. *Units used in Chapter 3*

The units of concentration used in the presentation of data for contaminants in sea water are: 1 μg/l (microgram per litre) representing a concentration of one millionth of a gram of material dissolved in one litre of sea water; 1 ng/l (nanogram per litre), a thousandth part of that concentration; and 1 pg/l (picogram per litre) representing a further reduction in concentration by one thousand times.

For sediments, concentrations of metals are expressed in mg/kg (milligram per kilogram), which represents one thousandth of a gram of a metal contained in one kilogram of dry sediment; concentrations of organic contaminants are expressed in μg/kg (microgram per kilogram), which represents one millionth of a gram of contaminant contained in one kilogram of dry sediment.

For biota, contaminant concentrations are expressed in mg/kg (one thousandth of a gram of contaminant contained in one kilogram of fresh (wet) tissue) or in μg/kg (one millionth of a gram of contaminant contained in one kilogram of fresh (wet) tissue).

Nutrient concentrations are expressed in μmol/l (micromole per litre), which is one millionth of the molar weight in grams of the nutrient dissolved in one litre of sea water.

Box 3·3. *Background concentrations of natural compounds*

The background concentration of a natural compound is defined as the concentration of that compound that would be found in the environment in the absence of human activity. Natural compounds are defined as all compounds produced from natural precursors by biosynthesis or by geochemical, photochemical, or chemical processes.

Where appropriate, background concentrations of various natural compounds (Box 3·3) are indicated. Such information is of particular importance for assessing the anthropogenic influence on present concentrations of contaminants in marine media.

Spatial and temporal distributions of chemical components in sea water

pH

From an environmental viewpoint, pH can be considered as a measure of the acidity of, for example, sea water. Although problems related to acid rain have been experienced in terrestrial and freshwater environments in several European countries in recent decades, in the marine environment such influence is expected to be insignificant owing to the high buffering capacity of sea water. Most of the pH measurements were carried out in coastal areas and estuaries where it was expected that the effects would first be evident, as these areas usually have a lower buffering capacity due to the mixing of sea water and river water. Available time series show a normal seasonal variation in pH, with values increasing in the surface water for a short time as a result of primary production (see Chapter 4).

Metals

This section will focus on dissolved metals that are considered contaminants (cadmium, copper, mercury, arsenic, lead, nickel, and zinc). These metals stem from significant anthropogenic as well as natural sources (Box 3·4). Data are also available for metals such as iron and manganese in some of the subregional assessment reports. Concentrations of most dissolved trace metals are higher in rivers than in oceans, and rivers generally constitute the dominant source of dissolved metals in sea water. Atmospheric input is also important and is thought to be the dominant source for some metals, including lead and cadmium.

The data reported here have been drawn primarily from the 1985–1987 ICES Baseline Study of Trace Metals in Coastal and Shelf Sea Waters (ICES, 1991a), which included a significant amount of data from the Joint Monitoring Programme (JMP) of the Oslo and Paris Commissions, and also from the German ZISCH Project (Circulation and Contaminant Transfer in the North Sea) for Subregions 1, 2, 3a, 6, 7a, and 7b, and the Skagerrak (data on near-coastal samples from this project were not used as the samples had not been filtered). In addition, some data were derived from the United Kingdom North Sea Project of 1988–1989 and from the individual subregional assessment reports. Data were available for all subregions except the Wadden Sea (Subregion 10), where metal concentrations are difficult to assess owing to their high variability and problems in normalization for salinity and suspended matter. Table 3·1 indicates the range of concentrations in non-estuarine locations recorded in the subregional assessment reports and the Baseline Study for the period 1985–1991. Data for unfiltered samples are excluded in the

Box 3·4. *Metals in the environment*

The presence of detectable concentrations of metals in the environment does not necessarily indicate the existence of contamination. With the exception of certain radionuclides, the ubiquitous presence of metals in water, sediments, and the atmosphere is unavoidable owing to their natural occurrence in the earth's crust. At their natural concentrations metals play an essential role in many biochemical processes; organisms are able to adapt themselves at least partly to changing metal levels.

Human activities have increased the rate of natural weathering and consequently the rate at which metals are introduced to the environment by natural processes. This is particularly true in industrialized countries such as those bordering the North Sea. Concern over the extent to which these enhanced inputs might be affecting the North Sea ecosystem have stimulated considerable research aimed at elucidating both present concentrations and the processes controlling them.

Metal inputs via a particular pathway are subject to a variety of processes that ultimately determine their fate. For example, some part of any enhanced dissolved metal inputs from rivers is likely to be removed through interaction with suspended particulate matter in estuaries. The subsequent movement of this material will have a strong influence on the ultimate fate of the adsorbed metal. Even a simple comparison of metal concentrations in water or sediments must therefore take into account the possible processes likely to affect them. The extent to which these factors may vary geographically as a result of differences in, e.g., salinity, turbidity of the water, or clay content of sediments, must also be considered.

case of mercury and lead, which are highly particle-reactive, except where concentrations of suspended particulate matter are known to be low. Offshore trace metal concentrations were generally lowest in the Channel and the northern North Sea, where a large proportion of the water is of Atlantic origin. Little information is included on temporal trends in concentrations of metals in sea water, as few appropriate time series are available.

Table 3·2 shows the ranges of dissolved trace metal concentrations observed in offshore surface waters of the North Sea and the Channel, and a number of North Sea estuaries, along with average values for ocean water. For cadmium, copper, nickel, and zinc, the lowest values recorded were close to the average ocean values, whereas for lead they were five to ten times higher. Estuarine trace metal concentrations were not always elevated, but concentrations were more variable than those seen offshore, and the mean values were higher than offshore values by a factor of two to greater than ten.

The concentrations reported below are mainly based on the report of the ICES Baseline Study, as it includes a review of data comparability and quality.

Table 3·1. Concentrations of dissolved metals (µg/l) in NSTF subregions (excluding estuaries), 1985–1991, as reported in subregional assessment reports, and ICES (1991a).

	Subregion				
	1 Northern North Sea	2a+b Northern North Sea	3a+b East coast of United Kingdom	4 Dutch and Belgian coasts	5 German Bight and Danish coast
Arsenic	n.r.	n.r.	n.r.	n.r.	n.r.
Cadmium	0.004–0.016	0.004–0.024	0.004 –0.026	0.02–0.05	0.01–0.04
Copper	0.02 –0.41	0.11 –0.42	0.1 –0.7	0.3 –1.0	0.16–1.1
Lead	0.02 –0.1	0.036–0.051	0.020 –0.081	0.03–0.12	n.r.
Mercury	0.001–0.003	0.003–0.008	0.0005–0.005	n.r.	n.r.
Nickel	n.r.	0.16 –0.30	0.14 –0.7	n.r.	0.24–1.4
Zinc	n.r.	n.r.	0.3 –1.4	n.r.	1.0 –5.0
	6 Coast of Norway	7a+b Central North Sea	8 Skagerrak and Kattegat	9 Channel	10 Wadden Sea
Arsenic	n.r.	n.r.	n.r.	1.2 –1.7	n.r.
Cadmium	<0.001–0.035	0.006–0.09	0.005–0.027	0.01 –0.03*	n.r.
Copper	0.02 –0.31	0.10 –0.47	0.095–0.54	0.11 –0.48**	n.r.
Lead	0.012–0.08	0.017–0.22	0.019–0.082	0.023 –0.069	n.r.
Mercury	0.001–0.003	0.005–0.008	0.001–0.005	0.0003–0.0005	n.r.
Nickel	n.r.	0.1 –1.5	n.r.	0.22 –0.47	n.r.
Zinc	n.r.	0.16 –1.4	n.r.	0.22 –1.0	n.r.

The range of concentrations was not always reported.
* minimum value estimated (mean – 1 standard deviation);
** maximum value estimated (mean + 1 standard deviation);
n.r.: not reported.

Table 3·2. Concentrations of dissolved metals (µg/l) in selected North Sea estuaries and offshore surface waters.

Area	Cadmium	Copper	Lead	Nickel	Zinc
Average Ocean	0.005–0.01	0.07–0.15	0.001–0.014	0.2	0.1
Offshore English Channel	0.011–0.015	0.2 –0.5	0.024–0.032	0.2–0.4	0.2–0.9
Offshore North Sea	0.01 –0.023	0.1 –0.4	0.021–0.081	0.2–0.7	0.3–1.4
Skagerrak and Kattegat	0.015–0.033	0.34–0.83	0.024–0.16	n.r.	n.r.
Elbe Estuary	0.018–0.051	0.4–2.3	n.r.	n.r.	n.r.
Western Scheldt	0.15	2.0	0.4	n.r.	n.r.
Tay Estuary	0.003–0.3	0.2–1.6	0.005–1.0	0.13–0.83	0.059–7.6
Forth Estuary	0.003–0.25	0.2–2.4	0.02 –0.37	0.13–1.5	0.12 –4.9
Tweed Estuary	0.007–0.011	0.6–3.1	0.096–0.17	0.5 –0.8	0.6 –1.9
Tyne Estuary	0.011–0.13	0.3–1.6	0.086–1.1	0.4 –2.8	0.6 –22.0
Wear Estuary	0.013–0.025	0.3–1.3	0.069–0.41	0.5 –2.9	0.5 –6.1
Tees Estuary	0.02 –0.042	1.3–10.0	0.096–0.82	0.2 –2.8	2.6 –14.0
Humber Estuary	0.049–0.22	0.8–2.8	0.023–0.42	0.9–6.3	5.1 –13.0

Data for estuaries are not normalized against salinity, and the range given covers data for the entire estuary. Data for offshore areas relate to water of salinity > 34.
n.r.: not reported.

Mercury

For mercury, data reported indicated that the highest values averaged over each subregion in samples with a salinity of 30–35 in the North Sea were found in the north-central and central North Sea (Subregions 2b (8 ng/l), 7a (5 ng/l), and 7b (8 ng/l)); lower values were found in the coastal waters off Scotland, England, the Netherlands, and western Norway; and the lowest values were in the Channel (0.5 ng/l). Subsequent studies failed to confirm the presence of the elevated mercury concentrations over the Dogger Bank that had previously been reported.

Cadmium

Data showed that dissolved cadmium concentrations declined from 0.03–0.05 µg/l in coastal waters to 0.01–0.02 µg/l in the central and northern parts of the North Sea, similar to those reported for ocean waters (ca. 0.01 µg/l). Data from the Channel show concentrations between 0.01 and 0.03 µg/l, with higher values in the low-salinity water of the Baie de Seine. The maximum cadmium concentrations were often observed in mid-estuarine samples (mid-salinity), and these declined with increasing salinity towards offshore areas. Such an inverse relationship between salinity and dissolved cadmium indicates that, in this particular case, dilution and dissolution during early estuarine mixing are the dominant processes determining the concentrations of this metal at salinities higher than 20.

The United Kingdom North Sea Project provided some insight into the seasonal variation of trace metal concentrations in response to physical, chemical, and biological processes. Higher concentrations of dissolved cadmium (and zinc) found along the continental coast during the winter and spring of 1988/1989, and off southeastern England during the spring of 1989, may have resulted from increased inputs of riverine suspended particulate matter and the subsequent desorption of these trace metals from the particles.

Lead

The highest concentrations of dissolved lead in samples with a salinity of 30–35 were found in the central North Sea (Subregions 7a and 7b (mean for the data set: 0.06 µg/l)) rather than in the adjacent coastal areas, which emphasizes the dominance of atmospheric inputs to offshore areas mainly caused by leaded fuel. High concentrations (up to 0.2 µg/l) were observed in waters adjacent to the Tees Estuary, and inverse correlations between lead and salinity suggest that the Tees was the source of the lead. In contrast, a plume of elevated and variable concentrations to the northeast of the Humber

Estuary was tentatively ascribed to atmospheric inputs. A significant positive correlation with salinity was observed in the Humber plume, suggesting that extensive scavenging of lead also plays a role, especially in winter when loads of suspended particulate matter in the estuary are high. Concentrations of dissolved lead in the Channel were lowest in the eastern part (mean for the data set: 0.03 µg/l) in springtime, possibly owing to the removal of lead by phytoplankton during the spring bloom.

Copper

Dissolved copper concentrations of 0.1 to 0.4 µg/l were found in offshore areas of the North Sea, with the lowest concentrations occurring in the central part of the northern North Sea (Subregion 1 (mean for the data set: 0.11 µg/l)). Higher concentrations (mean values >1.0 µg/l) were observed in some near-coastal areas, such as the German Bight (Subregion 5). An examination of the relationship between dissolved copper and salinity (between 20 and 35) showed that copper concentrations decreased with increasing salinity. In the United Kingdom North Sea Project, only minor seasonal changes were apparent in dissolved copper concentrations, although calculations for each of the estuarine plumes showed maxima during the late summer, suggesting that the geochemical cycling of dissolved copper is influenced by processes common to all river systems.

Zinc

Data from the ICES study showed that the range of dissolved zinc concentrations is fairly narrow (1.6–2.2 µg/l) in coastal areas (Subregions 3a, 4, and 5) of the North Sea (salinity >30). In the major estuaries of the Southern Bight (Subregion 4) and along the east coast of England (Subregion 3b), mean concentrations can exceed 7 µg/l. Zinc concentrations reported for the Channel, however, are considerably lower (0.2–1.0 µg/l). During the United Kingdom North Sea Project, concentrations were found to be highest in spring, and at the northernmost sites studied, high surface concentrations relative to deeper waters were observed, suggesting that, as for lead, atmospheric inputs were important at this time.

Arsenic

Data on dissolved arsenic were reported from the Strait of Dover, where concentrations ranged from 1.2 to 1.7 µg/l (Table 3·1), similar to the background concentrations in Atlantic water (1.4 ± 0.1 µg/l). Low concentrations (1–1.5 µg/l) were also found in the Southern Bight and off the Dutch coast, except for the Western Scheldt Estuary, where the concentration was 5 µg/l.

Nickel

Data reported on dissolved nickel concentrations in the Channel showed low concentrations in the western and central Channel (0.1–0.25 µg/l), with higher concentrations in certain coastal areas. During the United Kingdom North Sea Project, nickel (and copper) concentrations consistently showed significant inverse correlations with salinity, an observation indicating the importance of freshwater inputs in determining the distribution of these metals.

Fluxes of trace metals from the Channel to the North Sea and within the North Sea

Calculations of trace metal fluxes through the Strait of Dover were made as part of the Fluxmanche programme, based on analyses conducted in 1990/1991. Total fluxes of cadmium and copper are important, and lead and zinc significant, relative to other inputs to the North Sea. Fluxes of cadmium, copper, nickel, and zinc were predominantly in the dissolved phase, whereas fluxes of particulate lead were substantially greater than the dissolved flux.

In the 1987 *QSR*, attention was drawn to a fairly constant (1979–1983) gradient in dissolved cadmium concentrations along the Danish west coast, increasing from around 0.025 µg/l in the north to around 0.045 µg/l in the south, which suggests the existence of a source of cadmium in the German Bight. In studies conducted between 1986 and 1990, cadmium concentrations varied from 0.012 to 0.04 µg/l along the salinity gradient from north to south down the Danish west coast, compared with values of 0.018–0.051 µg/l in the outer Elbe Estuary. Copper (0.16–1.1 µg/l) and nickel (0.24–1.4 µg/l) exhibited a distribution pattern similar to that of cadmium.

Trace organic contaminants

Under the Monitoring Master Plan, the only mandatory contaminants to be measured in sea water were α-HCH and γ-HCH (hexachlorocyclohexane). Accordingly, few data concerning trace organic contaminants in sea water were available for inclusion in this report. Owing to the lipophilicity of many of these compounds, they would have low solubility and primarily be associated with the suspended particulate phase (Box 3·5).

Hexachlorocyclohexanes (HCHs)

As a result of inputs from continental rivers, the highest concentrations of γ-HCH (lindane) are found in the southern North Sea and the German Bight. The distribution pattern of γ-HCH in the North Sea in 1986 (Figure 3·1A, next page) showed a gradient from low concentrations (0.2 ng/l) in the northwestern North Sea (similar to those found in open North Atlantic waters, and resulting primarily from atmospheric inputs) to more than 4 ng/l in the German Bight. In 1990/1991 (Figure 3·1B, next page) high concentrations of γ-HCH were seen in certain estuaries (e.g., up to 5.3 ng/l in the Humber Estuary and 15 ng/l in the Elbe and Weser estuaries) and close to the coast, with lower concentrations (generally 1 ng/l or less) at offshore locations in the North Sea and Channel. Time-series measurements made in the inner German Bight between 1980 and 1991 show that although γ-HCH concentrations declined as a result of a ban on the use of technical HCH, no clear trend could be seen for γ-HCH. For the Elbe Estuary, however, a downward trend was observed in γ-HCH concentrations between 1987 and 1991, reflecting the reduction in γ-HCH input to the Elbe. The elevated concentrations observed in the Western Scheldt in June 1991 were ascribed to seasonal inputs resulting from the agricultural use of lindane.

Box 3·5. *Trace organic compounds in the environment*

Unlike metals, there are no known natural sources of some organochlorine compounds such as PCBs, synthetic pesticides (e.g., DDT), and herbicides. Their occurrence in the environment is therefore entirely the consequence of their production and use by man, principally on land. Some organic contaminants do however have natural sources. For example, certain PAHs can be produced during combustion (e.g., in forest fires), and some simple compounds (e.g., methyl iodine and dimethyl sulphide) can be produced by marine plants.

Organic contaminants such as PCBs are highly stable and degrade only very slowly in the environment. Their widespread occurrence coupled with their persistence has led to concern over the possibility that these compounds may accumulate in more vulnerable compartments of the marine environment, such as in marine mammals, including seals.

As with metals, trace organic contaminants are subject to a variety of processes that influence their occurrence in the environment. Many of the compounds have low solubility in water and show a high affinity for adsorption onto sediments; once adsorbed their dispersion pattern will follow that of the sediment. Sediment movements are in turn affected by, e.g., tidal energy and such physical characteristics as grain size. These and other factors, including subtle differences in the behaviour of individual PCB congeners, necessitate a careful interpretation of basic information on concentrations.

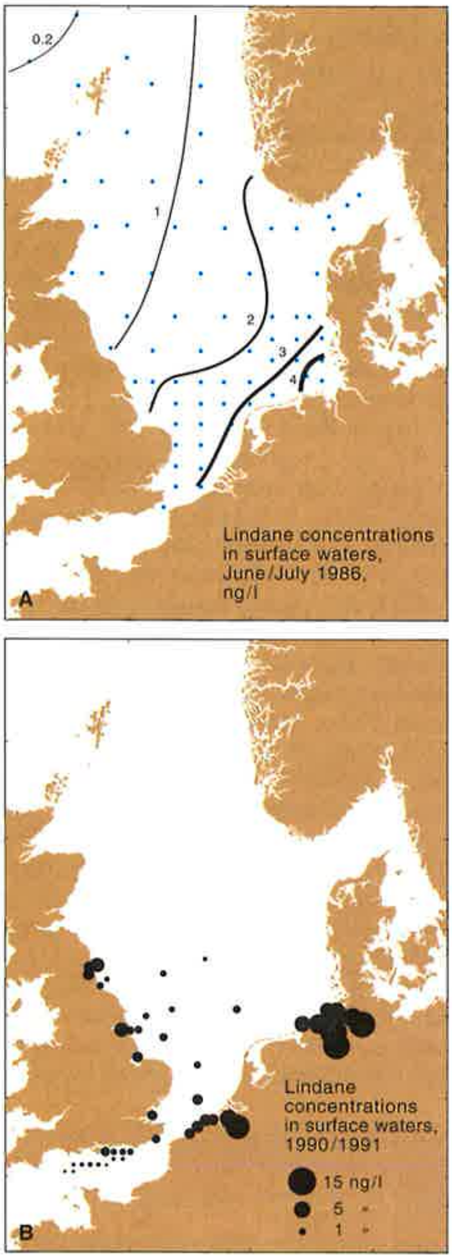


Figure 3·1. Concentrations of γ-HCH (lindane) in surface waters of the North Sea.
Source: ICES (1992).
A: June/July 1986: showing a gradient in concentration from the German Bight to the northern North Sea.
B: 1990/1991: coverage under the Monitoring Master Plan was incomplete; no samples were collected in the northern North Sea or the Skagerrak. Higher concentrations were apparent in estuarine and coastal areas than offshore.

Polychlorinated biphenyls (PCBs)

In this report, the terms 'polychlorinated biphenyls' and 'PCBs' are taken to refer to the industrial formulations (such as Aroclor 1254), with analyses conducted on a total basis, whereas the terms 'chlorinated biphenyls' and 'CBs' refer to a range of individual congeners that are separately determined. The sum of seven CB congeners (IUPAC CB Nos. 28, 52, 101, 118, 138, 153, and 180) in the dissolved phase ranged from 16 pg/l in French, Belgian, and Dutch offshore areas to 29 pg/l in northern Dutch coastal waters. These values are higher by a factor of two or more than those reported for surface waters of the Northeast Atlantic (west of the Bay of Biscay), namely, 3.2 to 12 pg/l. Subsurface water samples collected in 1988 along a series of transects in the North Sea and Channel showed that summed concentrations of the seven CBs were low in the Channel and the western-central North Sea (6.3 to 11 pg/l), similar to those obtained in 1986/1987 in the Northeast Atlantic, and somewhat higher (up to 33 pg/l) off Scotland and in the Southern Bight. The highest concentrations were found in the German Bight (up to 178 pg/l), with clear gradients to the west and northwest. A high concentration (83 pg/l) was also observed in the central North Sea along a transect traversing the area occupied by, among others, the Argyll, Auk, Ekofisk, and Fulmar oil fields. The pattern of CBs in this sample was different from those seen in other samples, but identical to PCB formulations such as Aroclor 1254 or Clophen A50. This suggests that the higher concentrations observed here may reflect recent inputs, possibly from oil industry production sites.

Tributyl tin (TBT)

A survey of imposex (a biological reaction to exposure to tributyl tin by some invertebrates) in the common dogwhelk *Nucella lapillus* at coastal and harbour stations was conducted in 1991/1992, using either wild or transplanted animals depending on the site. The results of the survey are provided in Section 5.3. The highest inferred concentrations were seen along the southern and eastern coasts of the North Sea, from Belgium to Denmark. Concentrations of dissolved TBT in the Western Scheldt and adjacent marine waters in 1988 were below 0.1 ng/l. In the Western Scheldt, there was a clear gradient of TBT concentrations in suspended particulate matter, from 850 to < 1 mg/kg from east to west (i.e., inshore to offshore).

In the United Kingdom, only 4 of 27 water samples taken at offshore locations in 1991 showed values above the limit of quantitation (reliable detection) for TBT, in the range 2 to 7 ng/l. Within estuaries, concentrations were generally higher (mean value approximately 6 ng/l) and often exceeded the Environmental Quality Standard (EQS) of 2 ng/l set in the United Kingdom. These results agree with those from previous shore-based surveys, indicating that since controls were instituted, TBT concentrations have decreased markedly at estuarine locations frequented by large numbers of yachts, although in harbours and dry-dock areas they are variable and often high.

Total hydrocarbons (THCs)

Total hydrocarbons (THCs) measured using fluorescence spectroscopy can provide some information on sources of petroleum hydrocarbon contamination. Such measurements showed an increase in hydrocarbon concentrations at two stations in the Kattegat. In 1990, concentrations of 70 and 33 µg/l were recorded at 10 m depth at Anholt and Vinga, respectively, compared with mean values slightly above 1 µg/l found during the 1980s. The high values recorded in 1990 are not typical of the stations considered. The THC concentrations found in surface waters at Anholt and Vinga in 1990, 1.3 and 1.6 µg/l, respectively, were similar to levels during the 1980s.

In the southern central North Sea (Subregion 7a) and off the west coast of Denmark (Subregion 5), THC concentrations between 0.2 and 2.5 µg/l (crude oil equivalents) were measured; in the Elbe Estuary, the values were much higher (e.g., 10–30 µg/l at Cuxhaven). Similarly, THCs in the Channel ranged from 0.3 to 2.6 µg/l, with typical values of 1 µg/l, but concentrations in surface waters exceeded 10 µg/l in the mouth of the Seine Estuary, where the highest concentrations (100 µg/l) were recorded upstream.

Aliphatic hydrocarbons from C_{11} to C_{18} are typical constituents of oil-based muds used in drilling offshore oil wells. For example, they have been measured around the Gorm platform at concentrations up to 635 µg/l, while background concentrations range from 1 to 11 µg/l (sum of aliphatic hydrocarbons).

Polycyclic aromatic hydrocarbons (PAHs)

Data for polycyclic aromatic hydrocarbons (PAHs) in sea water were available only for the Fluxmanche transect across the Strait of Dover. Samples were taken from 1 m below the surface and 3 m above the seabed in 1990/1991. Concentrations of individual PAHs and groups of alkylated PAHs ranged from 'not detected' to 410 ng/l, and observations suggested that inputs of oil from shipping made a significant contribution to sea-water PAH concentrations in this area. PAHs in sea water in the German Bight do not stem from shipping but from incomplete incineration processes, as determined from the spectrum of PAHs found. In suspended particulate matter from Dutch coastal waters in 1989/1990, concentrations of the sum of six PAHs (after Borneff) ranged from 1.3 to 3.0 mg/kg. Measurements of selected PAHs in the German Bight showed great differences in the concentrations of the individual PAHs and very great differences in the concentration gradients from the coast to the open sea.

Chlorobenzenes

Concentrations of chlorobenzenes (from a local industrial source) were determined in sea water in the Firth of Forth (Scotland). In 1987 very high concentrations of trichlorobenzenes and fairly high concentrations of hexachlorobenzene (HCB) were found. Subsequent surveys conducted in 1990 indicated that concentrations of chlorobenzenes had been reduced by a factor of 10 to 20, in line with reductions in inputs following the introduction of abatement measures. The observed ranges of concentrations in 1990 were: 1,2,4-trichlorobenzene, < 1.2–84 ng/l; 1,2,3-trichlorobenzene, < 1.2–51 ng/l; HCB, < 0.7–8.0 ng/l. These concentrations were below the relevant EC standards applied in the United Kingdom. The concentrations of trichlorobenzenes are three to four times higher than the maximum levels found in Dutch coastal waters in 1983–1984 at sites not known to be affected by local inputs.

Triazine herbicides

Atrazine and simazine are probably the most widely used of the triazine herbicides. Concern has been expressed that residues could be phytotoxic (i.e., toxic to aquatic plants) in freshwater and marine systems, since atrazine in the dissolved phase is resistant to both hydrolysis and photolysis. Atrazine is slowly degraded in sea water by microbial action and more rapidly hydrolysed in estuarine sediments. Only limited information is available for North Sea waters, but in Belgian coastal waters in 1990, concentrations of atrazine and simazine were generally below 0.05 µg/l, except for simazine close to the coast (0.08 µg/l). In the eastern part of the Western Scheldt, concentrations of atrazine and simazine were 0.3 and 0.1 µg/l, respectively; the latter value is below the Dutch Environmental Quality Standard for this substance. Determinations in estuaries in northeast England in 1991 showed concentrations of simazine in the range 0.004 to 0.01 µg/l and atrazine in the range 0.003 to 0.037 µg/l, that is, of the same order as those reported for Belgian coastal waters. In high-salinity waters of the Baie de Seine, concentrations of both atrazine and simazine were in the range 0.006 to 0.015 µg/l; however, higher concentrations were generally recorded upstream in estuarine waters, although they varied strongly with salinity and season.

Radionuclides

Natural radionuclides

Sea water contains natural radionuclides such as tritium, carbon-14, potassium-40, thorium-232, uranium-235, and uranium-238. Concentrations of radionuclides of the uranium and thorium series can be enhanced via industrial emissions to air and water, primarily from plants processing phosphate ores containing radium-226, lead-210, and polonium-210. Two such plants are situated on the Rotterdam Waterway, two on the Western Scheldt (near Vlissingen), and one on the Seine. Concentrations of radium-226 are increased three- to ninefold in the Western Scheldt, with lesser increases in lead-210 and polonium-210 also evident.

Artificial radionuclides

In addition to the global fallout from nuclear weapons tests, primarily in the 1960s, artificial radioactivity in the North Sea originates mainly from authorized releases from the nuclear reprocessing plants at Sellafield on the Irish Sea, Dounreay in northern Scotland, and Cap de la Hague on the Channel. Their effluents are carried into the North Sea by the prevailing water transport from the Irish Sea and the Channel. The western and central parts of the North Sea receive artificial radionuclides almost entirely from the inflow from the reprocessing plant at Sellafield, from two to four years after release. The discharges from Cap de la Hague are transported primarily by Channel water along the southern and eastern coasts, taking approximately one year to reach the German Bight (MAFF, 1991).

The temporal trends in concentrations of caesium-137 (^{137}Cs) show that activity concentrations in the central North Sea peaked in the late 1970s. Since then a significant decrease in ^{137}Cs concentrations has been observed, which is attributable to decreases in discharges from Sellafield. The discharges of ^{137}Cs from Cap de la Hague also decreased between 1984 and 1990. In 1984, the maximum activity concentration of ^{137}Cs in surface water was about 140 Bq/m^3; in 1990 the maximum concentration in the same area had dropped to 27 Bq/m^3 (Figure 3·2).

Releases from nuclear power stations normally contribute an almost negligible amount of radionuclides to the North Sea. The fallout from the Chernobyl accident in April 1986 led to a minor increase in radionuclides in the German Bight, the eastern central North Sea, and the area off Scotland; this contamination was removed in the course of the next two years via the Norwegian Coastal Current. However, the Skagerrak continues to receive Chernobyl-derived caesium isotopes in the outflow of water from the Baltic Sea, which received a significantly higher input from the accident.

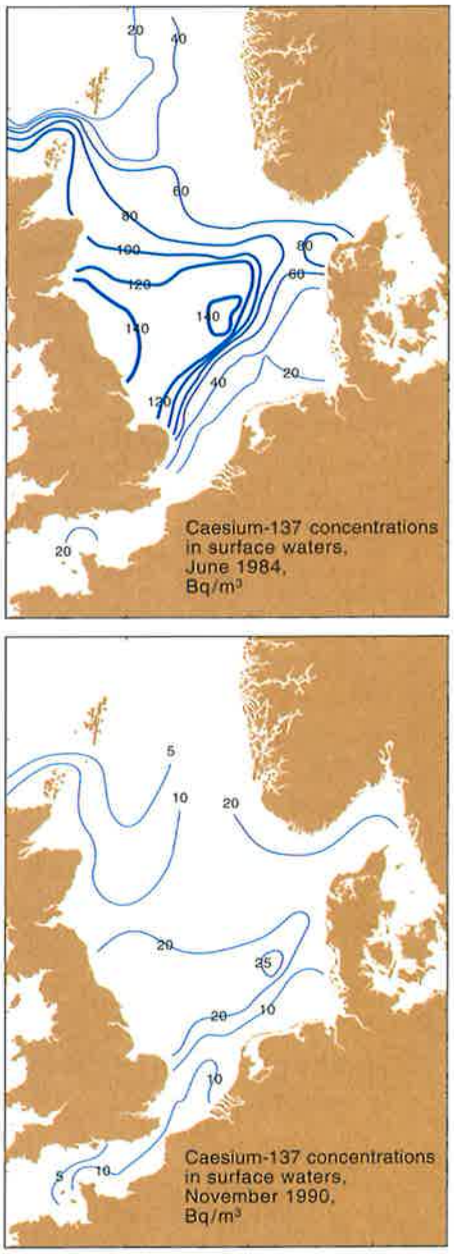


Figure 3·2. Distribution of caesium-137 in surface waters of the North Sea.

Spatial distribution of chemical components in sediments

Sediment studies in the North Sea have mainly been carried out to determine the spatial distribution of geochemical properties and contaminants. Temporal trend monitoring usually requires

Box 3·6. *The chemistry of bottom sediments*

The chemistry of bottom sediments is governed by several natural factors and is also subject to anthropogenic influences. Interpreting data on the chemistry of sediments requires that the relative influence of these factors be taken into account. The heterogeneity of the North Sea creates special problems owing to natural spatial variations. Investigations have been conducted in areas subject to erosion, transport, or deposition, with a wide range in grain size composition of sediments, and organic matter content. Because of geological differences in the catchment area of the North Sea, the mineralogy of the sediments shows large variations, with calcareous and sedimentary rocks as well as granitic rocks. Superimposed on these natural variations is the impact of anthropogenically introduced material, which varies according to the amount of material introduced, proximity to the source, and other factors.

The majority of anthropogenically released compounds show a strong affinity for particulate matter. As a result the chemical composition of bottom sediments reflects the input of anthropogenic substances to the marine environment. Studies of sediments in the North Sea have shown that estuaries and near-coastal areas represent sinks for contaminants, especially in areas where fine sediments are deposited, as well as deeper basins such as the Skagerrak Deep and the Norwegian Trench. Accumulation of contaminants in estuarine and coastal sediments may be linked to local point sources, while sediments in more remote areas will reflect the overall level of contamination.

Analyses of dated cores from deposition areas often indicate increases in the inputs of contaminants over the last 50 years. Because temporal trend monitoring in sediments requires the continuous accumulation of sediments and a minimum of disturbance by biological and anthropogenic activities, most of the North Sea, except the Norwegian Trench, is unlikely to be suitable for short-term trend studies.

good sediment cores suitable for dating and, in consequence, it is normally restricted to deposition areas. The main deposition areas in the North Sea are the inner Skagerrak, the Norwegian Trench, the Oyster Ground area of the German Bight, the Wadden Sea, and fjords and estuaries (Syvitski *et al.*, 1987) (Box 3·6).

When sediment geochemical data are interpreted in environmental studies, due consideration must be paid to background concentrations and natural variability. Table 3·3 shows the variability in background concentrations of trace metals in whole sediments from several regions. To compensate for this variability with respect to trace metals, normalization to aluminium or lithium is often carried out, as an indication of the proportion of fine-grained material to which contaminants are preferentially adsorbed (Loring, 1991). Grain size and origin are the two most important parameters requiring compensation by any normalization procedure. For organic contaminants, normalization to organic carbon may help in the interpretation of spatial variations. In contrast to trace metals, for trace organic compounds there are two possibilities:

1) synthetic organic chemicals, for which the natural background values are zero; and
2) trace organic compounds that have both natural and anthropogenic origins, such as polycyclic aromatic hydrocarbons, for which the natural background values are difficult to establish.

The description of the spatial distribution of chemical components in North Sea sediments is mainly based on the report reviewing the MMP data from the JMP/NSTF Baseline Study of Contaminants in North Sea Sediments, prepared by the joint ICES/NSTF/OSPARCOM ad hoc Working Group on Sediment Baseline Study Data Assessment (SEDMON) (ICES, 1994). Information is also included from the relevant sections of each of the subregional assessment reports.

Oxygen and redox conditions

Most of the seabed of the North Sea consists of sandy sediments with low organic matter content, over which frequent flushing of the bottom water occurs. Such conditions create well-oxygenated sediments and positive redox potentials in the upper centimetres of the sediments. Exceptions are silled fjords, estuaries, some near-shore deposition areas and deep basins or trenches (e.g., the Norwegian Trench), and areas in the immediate vicinity of salmon cage farms in inshore waters or around oil platforms.

Organic carbon

Terrestrial carbon plays a more important role in near-shore areas than in offshore areas. This is the case with respect to marine carbon as well, since the rate of production is often higher in near-shore waters owing to the higher concentrations of nutrients (Box 3·7). Organic carbon is also used as a normalizing factor, because organic matter is an important adsorber (scavenger) of trace metals.

Data submitted for the North Sea sediment baseline study (ICES, 1994) showed that the highest values of organic carbon were found in muddy sediments as, for example, those in the Skagerrak–Kattegat area and in fjords and estuaries. Few data were available for the southern North Sea and the Channel. Organic carbon concentrations in surface sediment samples from the North Sea were in the range 0.03 to 3.3%.

Box 3·7. *Organic carbon in sediments*

Organic carbon is an important parameter in sediments, both as an adsorber (scavenger) of contaminants and as an indicator of organic matter input (from land-based sources or *in situ* plankton production). There is normally a close relationship between the carbon content and the grain size of sediments. Fine-grained sediments, typical in areas of deposition, have a higher organic carbon content than coarse-grained sediments.

Four sources of organic carbon supply to North Sea sediments may be cited:

i) terrestrial carbon transported to the sea by rivers and to some extent by dumping of sewage sludge;
ii) carbon anthropogenically mobilized owing to incomplete combustion of fossil fuel and subsequent transport via the atmosphere;
iii) oil contamination from permanent installations and shipping activity;
iv) marine carbon generated by primary and secondary production.

Results from the most comprehensive study of organic carbon concentrations in whole sediments from the northern part of the North Sea (Basford and Eleftheriou, 1988) showed that the distribution of carbon closely followed that of the fine-grained material (and chlorophyll pigments). In this region, concentrations of carbon did not exceed 0.3%. Deeper areas (Moray Firth and Fladen Ground) showed higher concentrations (0.8 to 1.3%). The distribution pattern and association with pigment levels suggest that much of the carbon was derived from phytoplankton.

Table 3·3. Mean and ranges (± 1 standard deviation) of background concentrations of metals in marine sediments (in µg/g; Al in %). Source: Laane (1992).

Metal	Earth's crust	Humber sediments	Wadden Sea sediments	Norwegian coast sediments
Aluminium	6.93	7.1	4.8 ±0.2	5.8 ±1.6
Arsenic	7.9	22	13.5 ±1.3	–
Cadmium	0.2	–	0.5 ±0.01	0.08±0.02
Chromium	71	99	84 ±0.5	–
Copper	32	17	22 ±2.0	17 ±5.9
Mercury	–	–	0.067±0.009	0.04±0.03
Nickel	49	38	37 ±1.2	–
Lead	16	22	37 ±2.9	26 ±9.5
Vanadium	97	109	–	–
Zinc	127	84	103 ±5.2	110 ±27

Metals

The data assessed under the MMP by the SEDMON group, following checks on quality assurance, comprised about 6200 observations on total concentrations of trace metals in whole sediments (< 2 mm) and 4400 observations in fine sediments (< 63 µm and < 20 µm). Data were submitted for nearly thirty metals, but the coverage here will concentrate on the distribution of mercury, cadmium, lead, copper, and zinc (mandatory metals under the MMP), and arsenic, chromium, and nickel (optional metals under the MMP). The general distribution of samples taken for this study is shown in Figure 3·3.

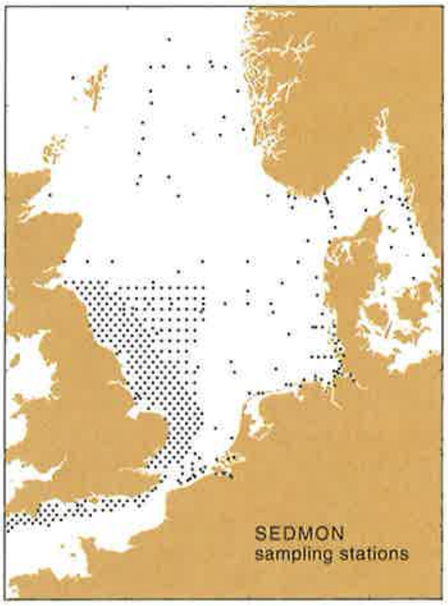


Figure 3·3. Sampling stations covered by the JMP/NSTF Baseline Study on Contaminants in North Sea Sediments (SEDMON). Source of data: ICES Data Bank on Contaminants in Marine Media.

Most of the data concern concentrations of trace metals in surface sediments (0–1 cm or 0–2 cm depth). This makes it possible to assess spatial distributions and to identify areas of special concern. Few core data are available, owing to a lack of suitable core sites with muddy sediments. However, some core data from the coastal area off Norway and from the Wadden Sea are included as examples. All concentration values for contaminants in sediments are given on the basis of the dry weight of the whole sediment, unless otherwise mentioned.

The concentrations reported below are based on data obtained using the agreed methods, including appropriate quality assurance procedures, for each contaminant. Mean concentrations are based on this set of accepted data, but with the elimination of concentrations below the detection limit and some particularly high concentrations which, although reliable, would have had an undue influence on the statistical treatment of the data. These high values are discussed separately. Some subregional assessment reports contain data sets that are not included because they do not comply with the above criteria or because they are not compatible (for example, they relate to different grain-size fractions); such data sets may, nonetheless, provide valuable supplementary information.

In addition, normalization has been applied to the contaminant concentrations to reduce concentration differences among samples of varying grain-size compositions, since contaminants are primarily associated with the fine fractions of the sediments. The concentration of aluminium has been used as one indicator of the amount of fine sediments in the sample. For other contaminants, particularly trace organics, the organic carbon content of the sediments has been used as the basis for normalization.

Mercury

Of the more than 600 samples studied, 19 samples contained mercury concentrations higher than 0.5 mg/kg; these were mainly from Norwegian fjords with local point sources, and from the Tyne and Thames estuaries. Statistical treatment of the mercury data (Figure 3·4A) shows that 75% of the mercury concentrations reported were below 0.025 mg/kg, which can be considered within the typical range. Sediments containing concentrations between 0.1 and 0.5 mg/kg were found on the south and southwest coasts of England and at a number of places along the east coast of England, in the estuaries of the Seine, Scheldt, Rhine, Weser, Elbe, and in the German Bight, the Dogger Bank area, the inner Skagerrak, and the Kattegat. This general distribution pattern, based on whole sediment analyses, shows no change after normalization of the concentrations, nor when data obtained from fine fractions are considered.

Accordingly, except for the area north of the Dogger Bank, the central parts of the North Sea have sediments containing mercury concentrations falling within typical ranges. This implies that most of the mercury discharged into the North Sea is trapped in estuaries and near-coastal areas, which is borne out by the elevated concentrations of mercury observed in the sediments in some Norwegian fjords, along the Swedish west coast, and in some English, French, Dutch, and German estuaries.

Cadmium

Areas with sediments containing high concentrations of cadmium (> 0.5 mg/kg) were reported in the Channel, both near the English coast and in the Baie de Seine, in the Western Scheldt Estuary, in the Wadden Sea, and in the Sørfjord in Norway (180 km inland from the coast). Excluding these high concentrations, cadmium concentrations in whole sediments from the North Sea ranged from 10 to 380 µg/kg (mean for the data set: 50 µg/kg); however, not all areas of the North Sea were covered.

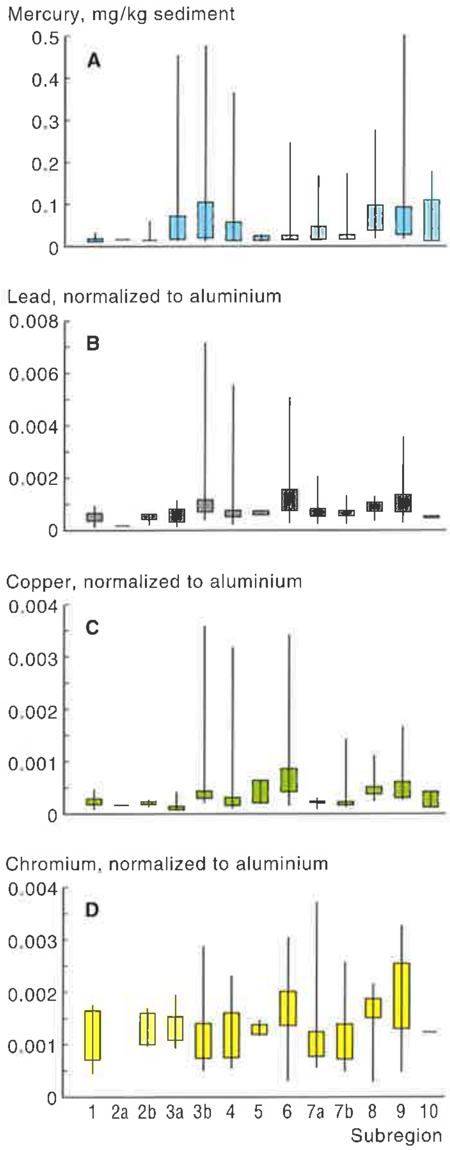


Figure 3·4. Concentration ranges and upper and lower quartiles for metals in surface sediments in NSTF subregions. Source of data: ICES Data Bank on Contaminants in Marine Media.

A: Mercury (in whole sediment, < 2 mm)
B: Lead in whole sediment normalized to aluminium (Pb/Al ratios for samples with Al ≥ 1%)
C: Copper in whole sediment normalized to aluminium (Cu/Al ratios for samples with Al ≥ 1%)
D: Chromium in whole sediment normalized to aluminium (Cr/Al ratios for samples with Al ≥ 1%)

The highest concentrations in this range were found in the Humber Estuary and on the northeast coast of England, and in the Western Scheldt. Some areas with elevated concentrations of cadmium were also found on the Dogger Bank. This preponderance of low values reflects the high proportion of sandy sediments in the North Sea. Normalized data show the same general distribution pattern.

In a separate study (Albrecht, 1992) based on the results of a German survey of the North Sea, an analysis of fine fractions of the sediment indicates that elevated concentrations of cadmium are found in the German Bight, particularly the inner part.

Lead

Very high concentrations of lead (up to 3 g/kg) were found in the Sørfjord/Hardangerfjord, Norway. Excluding these values, the lead concentrations in whole sediments of the North Sea were in the range 1.7 to 288 mg/kg (mean for the data set: 21 mg/kg). Of these, the higher concentrations were found in the Scheldt Estuary, the Baie de Seine, and on the northeast coast of England. The Norwegian Trench, the Skagerrak, the southwest coast of England, and the Humber and Thames estuaries also exhibited somewhat higher concentrations than the North Sea as a whole.

The high concentrations found in coastal areas are particularly associated with rivers that drain industrialized catchments. By contrast, the southwest coast of England has limited industry, but it is heavily mineralized and has a history of mining, particularly during the nineteenth century. Similarly, the northeast coast of England is heavily mineralized, and old lead mines affect the Tyne, Wear, and Tees estuaries in particular. Figure 3·4B shows the distribution of normalized lead (Pb/Al) in surface sediments of the subregions of the North Sea; the distribution is rather uniform, indicating that there are both land-based and atmospheric sources.

For the central part of the North Sea (in the Tails End region of the Dogger Bank and on the Great Fisher Bank), some coastal areas of eastern England, and the German Bight, the above-mentioned study by Albrecht (1992) shows higher concentrations of lead in the fine fraction (< 20 µm), although there is great variability in the data.

Copper

Very high concentrations of copper (up to 368 mg/kg) were found in sediments from the Sørfjord. Excluding these values, copper concentrations in whole sediments from the North Sea ranged from 0.1 to 87 mg/kg, with a mean for the data set of 14 mg/kg. Without normalizing for grain-size variations, copper concentrations in whole sediments were relatively high in some Norwegian fjords, the Norwegian Trench, the Skagerrak area, the Scheldt and Seine estuaries, and at various other locations, e.g., the Tyne and Tees estuaries in northeast England. Normalizing copper against aluminium shows the highest values in Norwegian fjords and the Scheldt Estuary, with high values also found off the Norwegian and Swedish coasts, including depositional areas in the Skagerrak and the Norwegian Trench, off the English coast near the Tyne, Tees, and Humber estuaries and East Anglia, and in a few areas off the southwestern coast of Denmark. A statistical treatment of these normalized data by subregion is shown in Figure 3·4C. Natural mineralization in certain areas, e.g., off the northeast coast of England, serves as a source of some of the copper found in the sediments.

Zinc

As with most of the other metals reviewed here, very high concentrations of zinc were found in the Sørfjord (up to 2 g/kg). Excluding these, concentrations of zinc in whole sediments from the North Sea were in the range 3 to 510 mg/kg, with a mean for the data set of 39 mg/kg. Relatively high concentrations are found in coastal areas, particularly in fjords, including the Hardangerfjord and the Oslofjord, and in the Scheldt, Seine, Humber, Tyne, and Tees estuaries. German research based on analysis of fine fractions shows relatively high concentrations of zinc in sediments from the Elbe and German Bight.

Arsenic

Data on arsenic concentrations in sediments were only available from the northern and eastern areas of the North Sea, including the Skagerrak and Kattegat. Concentrations were in the range <1.2 to 33 mg/kg, with a mean for the data set of 11 mg/kg. On the basis of whole sediments, the highest concentrations were found in the sediment accumulation areas of the Skagerrak. Normalization of arsenic concentrations to aluminium showed that sediments in the more sandy areas off the west coast of Denmark north of the German Bight, and at two stations close to the west coast of Norway outside the Sognefjord, have arsenic values similar to those found in the accumulation areas of the Skagerrak.

Chromium

The highest concentrations of chromium in whole sediments were found in the southern part of the North Sea, with somewhat elevated concentrations found near the coast of England, in the Skagerrak, and in the Norwegian Trench. After normalization to aluminium, these variations are less apparent, but higher chromium values are indicated on the Dogger Bank. Figure 3.4D shows the results of statistical treatment of these normalized data by subregion.

Chromium concentrations in the < 20 µm fraction, measured independently of SEDMON, show the highest values in the central North Sea, associated with areas of higher levels of organic carbon in this fraction.

Nickel

Information on nickel concentrations in sediments was mainly provided for the northern and eastern areas of the North Sea. Concentrations in whole sediments ranged from 1.5 to 113 mg/kg, with a mean for the data set of 23 mg/kg. The distribution in whole sediments indicated that the highest concentrations occurred in certain Norwegian fjords, the Norwegian Trench, and the Skagerrak area. A similar pattern was shown for values normalized to aluminium. However, normalization to organic carbon resulted in nickel values for the Skagerrak that were no longer enhanced in relation to those of other areas. Thus, the higher levels of nickel in the Skagerrak appear to be associated with the enhanced concentrations of organic carbon in this area.

Trace organic contaminants

Difficulties were experienced in obtaining a satisfactory picture of the distribution of trace organic contaminants in sediments over the entire North Sea, owing to the limited sampling coverage in some areas, a lack of information on quality assurance, and the use of non-comparable methods or methods with limits of quantitation which were not sufficiently low. Under the Monitoring Master Plan, measurements of selected chlorobiphenyl congeners (IUPAC CB Nos. 28, 31, 52, 101, 105, 118, 138, 153, 156, and 180) and hexachlorobenzene (HCB) were considered mandatory in sediments. Some laboratories also measured optional determinands such as DDTs, the 'drin' group of pesticides, chlordanes, and selected polycyclic aromatic hydrocarbons (PAHs). Data presented here concern contaminant concentrations on a dry weight basis.

Chlorinated biphenyls (CBs)

Information was available on only six of the recommended chlorobiphenyls (CBs 28, 52, 101, 138, 153, and 180), and the spatial coverage was generally inadequate. On the basis of a statistical review of the data, it was found that CB153 showed a close correlation with the other CBs measured, except for CB52, and exhibited similar correlations with grain size and organic carbon. Accordingly, CB153 has been used as a CB representative of the others, with the exception of CB52, which is covered separately.

CB153 concentrations were reported in the range 0.01 to 11 µg/kg, with a mean for the data set of 0.57 µg/kg. Concentrations of CB153 are highest in the coastal regions of the southeastern part of the North Sea, in particular on the coast of Belgium and in the Scheldt Estuary; along the German coast, including the estuaries of the Ems, Weser, and Elbe; and in the deeper deposition areas in the Skagerrak and the Norwegian Trench. Somewhat higher concentrations were also found off the southwest coast of Norway and, to a lesser extent, off the coast of Scotland. After normalization to organic carbon, the highest concentrations of CB153 were found in the Ems Estuary, followed by the Western Scheldt and Elbe estuaries; other areas showed less marked differences. No data were available for Dutch or Danish coasts. Data submitted by the United Kingdom showed concentrations below 2 µg/kg.

Of the CBs reported for the MMP, CB138 exhibited the highest mean concentration for the data set, 0.64 µg/kg, with a range of 0.01 to 9 µg/kg. CB101 was found at somewhat lower concentrations, ranging from 0.01 to 5.5 µg/kg, with a mean for the data set of 0.41 µg/kg.

CB52 is a lower-chlorinated CB and can be expected to be less persistent in sediments (water solubility of the individual congeners decreases with increasing chlorination level). Concentrations of CB52 are also lower than those of CB153 and CB138 because the initial distribution of congeners in the technical mixtures is different. This is borne out by its somewhat lower concentrations in the sediments sampled in the North Sea, with a range from 0.01 to 3 µg/kg, and a mean for the data set of 0.21 µg/kg. The distribution of CB52 in the sediments is, however, roughly similar to that of CB153, with the exception of the area around Belgium, which seems to have relatively low CB52 levels. Normalization of CB52 concentrations to organic carbon showed the highest values in the Ems Estuary, followed by the Western Scheldt and Elbe estuaries. The other lower-chlorinated CB measured, CB28, was found at levels similar to those of CB52, ranging from 0.01 to 3 µg/kg, with a mean for the data set of 0.26 µg/kg.

Thus, the CBs generally follow the same spatial distributions as those observed for trace metals, with higher concentrations found in deposition areas where fine-grained sediments with higher concentrations of organic matter accumulate.

Hexachlorobenzene (HCB)

The distribution of hexachlorobenzene (HCB) in North Sea sediments appears to be similar to that of the CBs, although lack of data from some areas does not permit a complete picture to be drawn. Concentrations ranged from 0.01 to 4 µg/kg, with the highest values in the Elbe and Ems estuaries and slightly lower values off the coast of Germany, in the Weser Estuary, in the Skagerrak, and in the inner Oslofjord. HCB concentrations normalized to organic carbon showed that the highest values were in the Ems Estuary, followed by the Elbe Estuary; slightly elevated values were also found in parts of the Skagerrak. In the area east of Shetland, concentrations of HCB in surface sediments were generally close to or below the limit of quantitation (0.01 µg/kg). These concentrations reflect non-localized inputs, e.g., from the atmosphere or long-range transport of particulate-bound contaminants. In contrast, concentrations in the range 0.06 to 0.28 µg/kg have been measured in sediments from the Skagerrak, and around 3 µg/kg along the Dutch coast.

Polycyclic aromatic hydrocarbons (PAHs)

Data were submitted on a fairly large number of polycyclic aromatic hydrocarbons (PAHs). After conducting a statistical review of the data, the following compounds were chosen as representative of various types of PAHs: benzo[*a*]pyrene (BAP), a high molecular weight PAH mainly produced during combustion; phenanthrene (PA) and naphthalene (NA), lower molecular weight compounds arising from combustion and oil sources; and C_1-alkyl derivatives of naphthalene (NAPC1), representative of oil sources.

With the exception of the Western Scheldt, most samples were taken in the central and northern North Sea and the Skagerrak and Kattegat. Concentrations of benzo[*a*]pyrene were in the range 0.0006 to 0.24 mg/kg, with the distribution showing the highest concentrations in the Western Scheldt, the Skagerrak, the Kattegat (including along the Swedish coast), the Oslofjord, and the Hardangerfjord. Normalization to organic carbon evened out some of the differences, leading to a relative decrease in the values in the Skagerrak and Kattegat and to higher values for sediments in the central parts of the North Sea (especially Subregion 7a).

Concentrations of phenanthrene ranged from 0.001 to 0.15 mg/kg, with the highest values in the Skagerrak, Oslofjord, and Kattegat; the results of normalization to organic carbon were similar to those with benzo[*a*]pyrene. Concentrations of naphthalene ranged from 0.001 to 0.055 mg/kg, and the distribution was similar to that of phenanthrene, also after normalization to organic carbon. Concentrations and distributions of the C_1-alkyl derivatives of naphthalene were similar to those for phenanthrene.

Total hydrocarbons (THCs)

The most important source of hydrocarbons from offshore oil activities are the drilling muds used in drilling wells. A considerable amount of pollution by hydrocarbons is found around platforms where oil-based drilling muds are used. The pollution gradient away from the platform is generally very steep: oil concentrations observed within a distance of 0.5 to 1 km from the platform are 100 to more than 1000 times higher than typical background values in remote areas (0.2–5 mg/kg dry sediment). For some platforms, elevated concentrations have been reported as far as 5 km from the site, and for one platform in the Norwegian sector, elevated concentrations could be detected out as far as 7 km.

Octachlorostyrene

Octachlorostyrene, formed as a by-product during certain high-temperature industrial processes, enters the marine environment via waste water and atmospheric deposition. Concentrations higher than those found elsewhere have been observed in sediments (and biota) near the former incineration area in the North Sea and also in the German Bight and the Norwegian Trench.

Other organic contaminants

In addition to the contaminants covered above, some data were submitted for the JMP/NSTF Baseline Study on Contaminants in North Sea Sediments (ICES, 1994) for a number of other organic contaminants in marine sediments, including the DDT group, the chlordane group, hexachlorocyclohexanes, and dioxins and furans. Although the data were inadequate for conducting an assessment of the spatial distribution of these contaminants for the North Sea as a whole, their presence was detected in a number of the samples analysed.

Radioactive substances

Natural radionuclides

Natural radionuclides present in sediments are predominantly potassium-40, and uranium and thorium and their decay products. Fine-grained sediments show the highest specific activity compared with coarser particles. Typically, the specific activity of potassium-40 is between 100 and 700 Bq/kg; of thorium-232 and its decay products, between 12 and 50 Bq/kg; and of uranium-238, up to 190 Bq/kg.

Artificial radionuclides

The radionuclides of greatest potential significance for public exposure are caesium-134 (^{134}Cs) and caesium-137 (^{137}Cs); however, their environmental concentrations are very low. The specific activity of ^{134}Cs and ^{137}Cs in North Sea sediments decreased between 1986 and 1991, a major source of contamination being the Chernobyl fallout in 1986. Along the North Sea coast of the United Kingdom, the highest specific activity was determined in muddy sediments in 1987, with values of 65 and 6.0 Bq/kg for ^{137}Cs and ^{134}Cs, respectively. Caesium-137 in surface muddy sediments from the German Bight was measured at up to 20 Bq/kg in 1990. Muddy sediments from the Skagerrak showed a specific activity up to 30 Bq/kg for ^{137}Cs in the surface layer.

Spatial distribution and temporal trends of chemical contaminants in biota

The information presented below on the spatial distribution of contaminants in biota in the North Sea stems from the 1990 OSPARCOM Supplementary Baseline Study of Contaminants in Fish and Shellfish and the 1985 ICES/OSPARCOM/HELCOM Baseline Study of Contaminants in Fish and Shellfish in the North Atlantic (ICES, 1988), and from additional material furnished in subregional assessment reports. The main species covered are common dab (*Limanda limanda*), Atlantic cod (*Gadus morhua*), whiting (*Merlangius merlangus*), European flounder (*Platichthys flesus*), European plaice (*Pleuronectes platessa*), and blue mussels (*Mytilus edulis*). In order to summarize the information, data on individual contaminants in a particular tissue have been grouped together for several species where feasible, e.g., contaminants in fish muscle tissue. Data on blue mussels (hereafter referred to simply as mussels) concern the soft body tissues.

Temporal trends of contaminant concentrations in fish and shellfish have been studied by ICES and the JMG for a number of data sets in the North Sea covering the period 1978 to 1988 (ICES, 1989; ICES, 1991b). Statistical models have been developed to obtain the best estimate of trends, taking into account a number of factors, including biological characteristics of the fish and shellfish sampled (sex, age, size, etc.), and seasonal and year-to-year variations that affect the uptake and release of contaminants. These studies have shown that few clear trends can be observed in the concentrations of contaminants in biota over the restricted time periods studied.

Concentrations presented are given in mg/kg wet weight unless otherwise stated. For fish and shellfish an approximate conversion to mg/kg dry weight can be achieved by multiplication by a factor of 5.

Metals

Information on the concentrations of mercury in fish muscle and of cadmium, lead, copper, and zinc in fish liver tissue obtained from subregional assessment reports is shown in Figure 3·5. Concentrations of these contaminants in mussels, compiled from subregional assessment reports, are depicted in Figure 3·6.

Mercury

Mercury concentrations in fish muscle (dab, whiting, and cod) were in the range 0.03 to 0.22 mg/kg wet weight. Within this range, higher concentrations were found in fish from the eastern Channel, the Southern Bight (including the area off the Thames Estuary), the Humber Estuary, the Ems Estuary, the area northwest of Terschelling, the Oyster Ground, the German Bight, and the Sørfjord. In addition, cod from the northeastern Kattegat showed high concentrations of mercury (0.32 mg/kg wet weight).

In mussels, mercury concentrations ranged from 0.002 to 0.17 mg/kg wet weight, with concentrations at the higher end of this range found in the Southern Bight, the Wadden Sea, the Ems Estuary, the Western Scheldt, at various locations along the coast of England (including the Tyne Estuary, the area off the Tees Estuary, the Humber Estuary, and the area off the Thames Estuary), at the entrance to the Limfjord on the west coast of Denmark, and in the Sørfjord and Hardangerfjord.

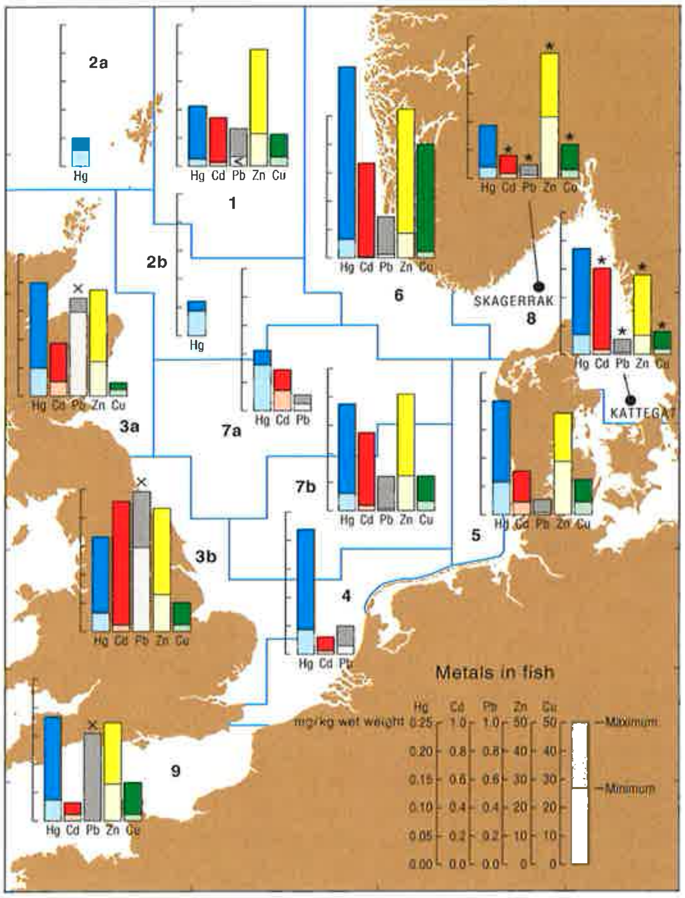
Temporal trend studies indicate a downward trend between 1982 and 1988 in concentrations of mercury in the muscle of cod and plaice from the Leman Bank/Smith's Knoll area. However, there was no indication of significant trends in the concentrations of any other trace metals in fish or shellfish samples from the east coast of England. Similarly, a linear trend with a downward tendency has been shown in mercury concentrations in the muscle of cod and plaice from the coast of Belgium, over the period 1978 to 1988.

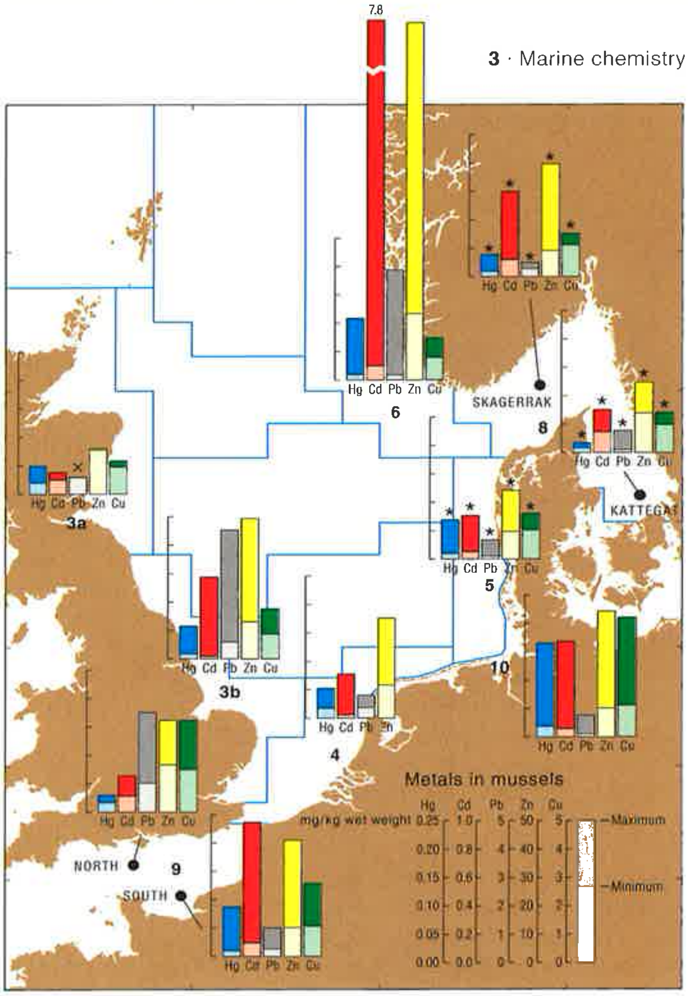
Data on mercury concentrations in the muscle of cod and flounder from the Oslofjord have shown evidence of a linear trend with an upward tendency from 1981 to 1988. Two of three fish species analysed in the Kattegat (herring and dab) indicate upward trends of mercury concentrations in muscle; the third species, cod, shows mercury concentrations fluctuating over the years, with no evidence of a trend.

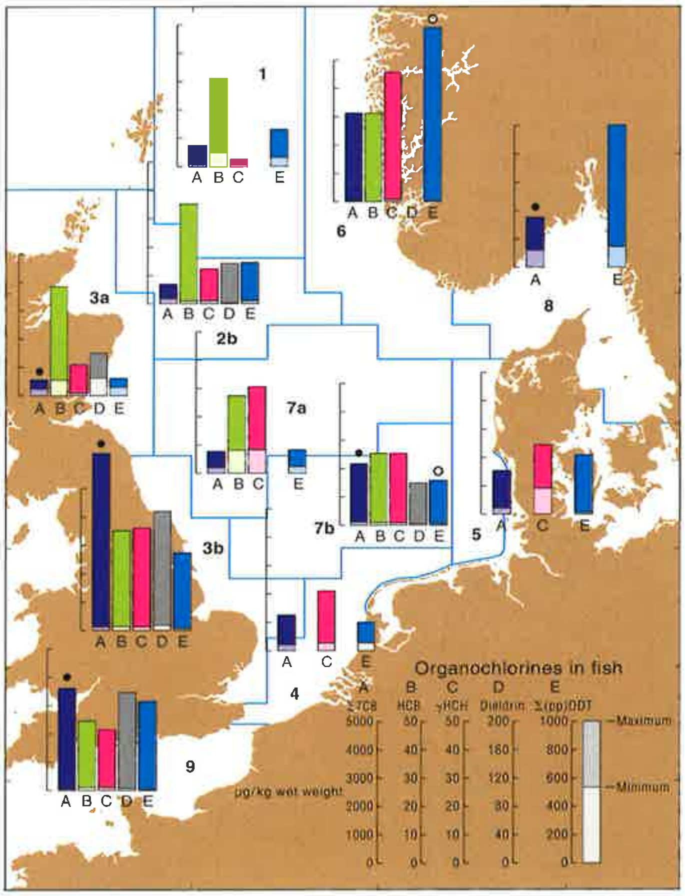
Cadmium

Concentrations of cadmium in fish liver (dab, whiting, and cod) generally ranged from 0.02 to 0.66 mg/kg wet weight. Within this range, higher concentrations were found in fish off the east coast of England, including the coast of Yorkshire, the Tees Estuary, and the offshore Wash area, and several locations near the Dogger Bank, including the Outer Silver Pit area. A higher concentration (0.96 mg/kg) was found in a sample of dab offshore the Humber Estuary; however, subsequent studies showed lower concentrations.

Cadmium concentrations in mussels were generally in the range < 0.06 to 0.94 mg/kg wet weight. Within this range, the highest concentrations were found in the Humber area off the east coast of England, in the Western Scheldt Estuary, along the French coast between the Seine and the Belgian border, and in the Elbe Estuary. In addition, mussels in the Sørfjord and inner parts of the Hardangerfjord in Norway contained very high concentrations of cadmium, from 2.0 to 7.8 mg/kg wet weight; the Sørfjord is an exceptional hot spot area which has received discharges from the metallurgical industry for more than 60 years.







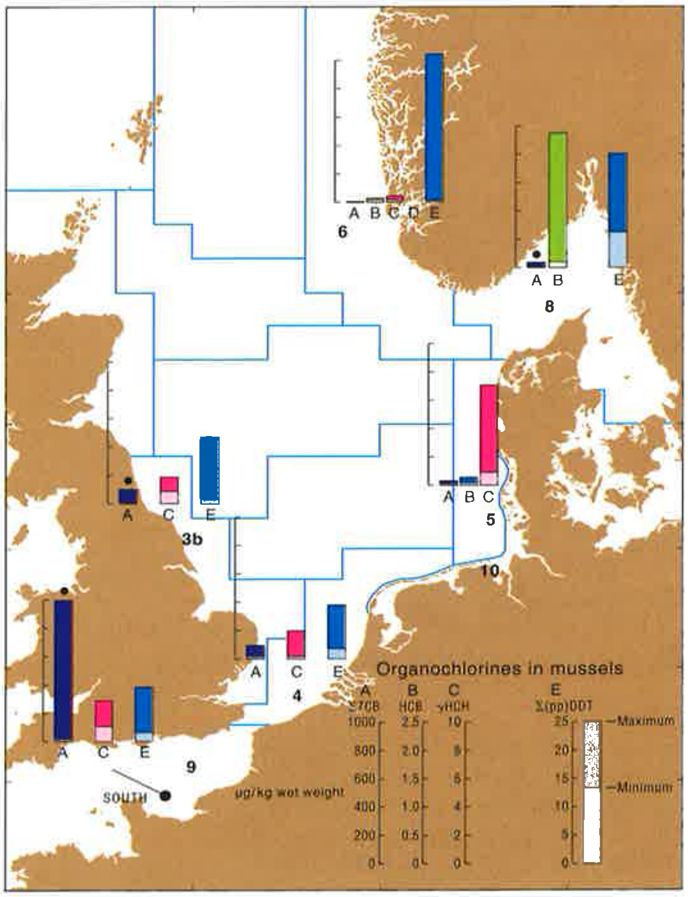


Figure 3·5. Concentrations of mercury in fish muscle and of cadmium, copper, lead, and zinc in fish liver (mg/kg wet weight) in NSTF subregions.
* Data reported on a dry weight basis have been converted to a wet weight basis; × Lead minimum and maximum values both qualified as 'less than'.

Figure 3·6. Concentrations of metals (mg/kg wet weight) in mussels (*Mytilus edulis*) in NSTF subregions.
* Data reported on a dry weight basis have been converted to a wet weight basis; × Lead minimum and maximum values both qualified as 'less than'.

Figure 3·7. Concentrations of organochlorines (µg/kg wet weight) in fish liver in NSTF subregions.
• PCB on a formulation basis; ○ DDE only.

Figure 3·8. Concentrations of organochlorines (µg/kg wet weight) in mussels (*Mytilus edulis*) in NSTF subregions.
• PCB on a formulation basis; ○ DDE only.

Temporal trend analyses for cadmium concentrations in mussels showed: 1) an increasing trend in the outer Seine Estuary, and 2) decreasing trends on the Fladen Ground and in the Kattegat, the Oslofjord, and the Langesundfjord.

For cod liver, cadmium concentrations showed a downward trend in the outer Oslofjord, whereas in the inner part there was an upward trend. Downward trends were also observed for cadmium in plaice from two stations in the Skagerrak off the northwest coast of Denmark.

Lead

Concentrations of lead in fish liver (dab, flounder, whiting, and cod) were in the range < 0.02 to < 0.8 mg/kg wet weight; for many samples, concentrations at or below the detection limits of the methods used were reported.

Lead concentrations in mussels were reported in the range 0.1 to 4.6 mg/kg wet weight. Areas with values in the upper part of this range include various locations along the northeast coast of England and four locations in the Sørfjord and inner Hardangerfjord.

Temporal trend studies have shown fluctuating downward trends in lead concentrations in the following cases:

1) in the liver of herring, dab, and cod, and in mussels from the Kattegat;
2) in the liver of cod and mussels from the outer Oslofjord, and in mussels from the inner Oslofjord;
3) in the liver of plaice off the west coast of Denmark and in two areas of the Skagerrak off the northwest coast of Denmark;
4) in mussels from the inner and outer Ems estuaries; and
5) in mussels from the coast of Belgium.

It has been postulated that these decreases in lead concentrations reflect reduced inputs owing to greater use of unleaded petrol in automobiles.

In contrast, upward trends in lead concentrations were noted in the liver of flounder from the inner and outer Elbe estuaries, and the Baie de Seine.

Copper

Concentrations of copper in fish liver (dab, whiting, and cod) ranged from 1.7 to 15 mg/kg wet weight. Within this range, areas with higher concentrations include the eastern, central, and western Channel, the Southern Bight, areas off the Thames, Tees, and Tyne estuaries, the Ems Estuary, the Oyster Ground, the Outer Silver Pit area, the mouth of the Oslofjord, and several locations off the south and west coasts of Norway.

Copper concentrations in mussels were reported in the range 0.8 to 4.2 mg/kg wet weight. Of these values, concentrations in the upper part of this range were found in the western Channel, the Western Scheldt Estuary, the Ems Estuary, off the East Frisian coast, in the outer Elbe Estuary and the inner Oslofjord, off the Norwegian coast around Arendal, in the Hvaler/ Singlefjord area, off the coast of Suffolk, and in the Humber Estuary.

Copper is an essential metal and can be regulated by organisms. Thus, there were no conclusive temporal trends observed in concentrations of copper, with the possible exception of concentrations in the liver of flounder and cod off the Belgian coast, which have shown a fluctuating downward trend since 1978.

Zinc

Concentrations of zinc in fish liver (dab, whiting, and cod) ranged from 6.6 to 43 mg/kg wet weight, with the higher values stemming from Smith's Knoll, the northern part of the Southern Bight, the Dogger Bank, the Outer Silver Pit area, and the Ems Estuary.

In mussels, reported zinc concentrations were mainly in the range 9.2 to 49 mg/kg wet weight. Areas with values at the higher end of this range included the Tyne Estuary, the Western Scheldt, the southwestern Channel, and several sites along the south and east coasts of Norway, the outer Oslofjord and the Sørfjord/Hardangerfjord. In Norway (five locations in the Sørfjord and Oslofjord), the Southern Bight, and the Western Scheldt Estuary, the concentrations of zinc in mussels ranged from 52 to 89 mg/kg, and at one station (Krossanes/Sørfjord) a concentration of 127 mg/kg was recorded.

As with copper, zinc is an essential metal and is known to be regulated by many marine organisms. Thus, it has been difficult to determine temporal trends for zinc in biota. In general there are few clear trends in zinc concentrations. However, two areas have been identified where upward trends for zinc in mussels exist: the Elbe Estuary and the Belgian coast.

Downward trends in concentrations of zinc were identified in the liver of plaice sampled off the west coast of Denmark and at two locations in the Skagerrak off the northwest coast of Denmark. Downward trends were also noted in two of the four species studied in the Kattegat.

Trace organic contaminants

Although some data were reported for a number of organic compounds, they were generally not sufficient to permit a discussion of the distributions of these contaminants in the North Sea as a whole. In addition a number of different tissue matrices were used by the reporting laboratories. Consequently only the data for CBs, PCBs, γ-HCH, dieldrin, and the DDT group are assessed in this report. Figure 3·7 shows the concentrations of these contaminants in fish liver tissue, and Figure 3·8 shows their concentrations in mussels, as compiled from subregional assessment reports.

Table 3·4 gives information on concentration ranges in various biological matrices of other organic contaminants for which considerably fewer data are available.

Polychlorinated biphenyls

The information reported concerns summations of concentrations of seven individual chlorobiphenyl congeners (CBs 28, 52, 101, 118, 138, 153, and 180), reported in biota tissue on a wet weight basis. Not all countries reported their

Table 3·4. Concentration ranges for various organic contaminants in individual NSTF subregions.

Contaminant	Subregion	Matrix used	Range, µg/kg
Chlordanes	1	Cod liver	8.8–52.2*
	6	Cod liver	11–113*
	8	Herring	18–79**
Aliphatic hydrocarbons	2a	Horse mussel	20–200*
	2b	Cod liver	0.6–82*
	2b	Cod muscle	0.2–3.3*
PAHs	2a	Horse mussel	406–1820*
Toxaphene	4	Cod liver	200**
	4	Mackerel and herring muscle	140–400**
	4	Marine mammal blubber	8700–27000**
	8	Herring	620–2200**
TCDDeq (dioxin equivalents)	4	Cod liver	0.058–0.17*
	8	Herring	0.27–2.1*
	8	Marine mammal	0.78–9*
TBDE (tetrabromodiphenyl ether)	4	Cod liver	120–240*
	8	Herring	59–450**
Chloronaphthalene	8	Herring	1.4–22**
Methylmercury	4	Shrimp, mussel	50–270**

* wet weight , ** lipid weight.

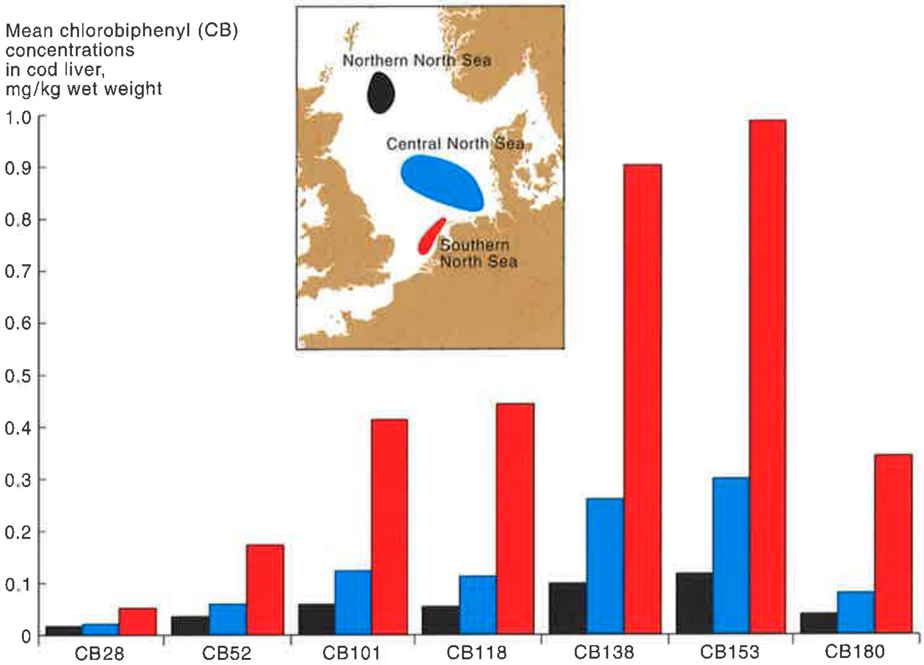


Figure 3·9. Concentrations of seven individual chlorobiphenyl congeners in cod liver from three areas of the North Sea (1979–1987), showing a gradient in concentration from north to south, towards the area of greatest inputs. Source: de Boer (1988).

PCB-related data as individual CBs, so the spatial coverage of the North Sea is incomplete. Concentrations for the sum of these seven chlorobiphenyls in fish liver (dab, cod, flounder, and plaice) ranged from 0.01 to 1.3 mg/kg wet weight as reported in subregional assessment reports. Within this range, the highest concentrations were found in the Sørfjord, the Karmøy region off the west coast of Norway, the Oslofjord, the Southern Bight, and the Western Scheldt Estuary. Figure 3·9 shows the concentrations of these seven CBs in cod liver from three areas of the North Sea, based on a different set of data.

Summed concentrations of the seven CBs in mussels were reported from 1.5 to 78 µg/kg wet weight. The highest concentrations were reported in the Western Scheldt Estuary, the Ems Estuary, and those areas of the Wadden Sea influenced by the rivers Ems, Weser, and Elbe.

Considering results based on the quantification of 'total PCBs' on a formulation basis (Duinker *et al.*, 1988), higher levels are also found in mussels from the Thames Estuary, the Baie de Seine, and a number of locations on the French coast of the Channel and on the Belgian coast.

With respect to temporal trends, the most obvious downward trends in concentrations of PCBs were in mussels from the Orkdalsfjord and the Oslofjord. Cod, flounder, and mussels from off the Belgian coast showed a downward, but fluctuating, trend. Concentrations of PCBs in cod liver from the Dutch coast decreased slowly but significantly between 1979 and 1991. There were no statistically significant upward trends in PCB concentrations.

Based on measurements of CB153, downward trends in concentrations were observed for plaice in the outer German Bight, flounder in the inner German Bight, and mussels from the Ems-Dollard Estuary and the outer Elbe Estuary.

γ-Hexachlorocyclohexane (γ-HCH)

Concentrations of γ-HCH (lindane) in fish liver (dab, whiting, cod, and plaice) were generally reported in the range <1 to 21 µg/kg wet weight. Within this range, higher concentrations were found at several locations in the Southern Bight, in the western Channel off Plymouth, and at several areas off the west coast of Norway (Farsund, Bomlo) and in the Sørfjord. In addition, concentrations of γ-HCH in whiting liver from three areas were clearly higher: 27 µg/kg off the Wash in England, 31 µg/kg in the Southern Bight, and 37 µg/kg in the outer Thames Estuary.

In mussels, γ-HCH concentrations were generally lower than 12 µg/kg wet weight; the highest concentrations were reported off the coast of East Friesland. Uniformly low concentrations of γ-HCH were found in mussels along the west coast of Norway.

With regard to temporal trends, downward trends in concentrations of γ-HCH were observed in flounder from the inner Elbe Estuary and the outer Elbe Estuary, as well as in mussels from the outer Elbe Estuary, and in plaice from the outer German Bight. There was also a significant downward trend of γ-HCH in mussels from the western part of the Baie de Seine. An upward trend in γ-HCH concentrations was found in flounder from the Ems Estuary.

Dieldrin

Concentrations of dieldrin measured mainly in fish liver (dab and whiting) ranged from 2 to 170 µg/kg wet weight. Data were mainly obtained from the United Kingdom for the central and southern North Sea. Within this range, the higher levels were found in the outer Thames Estuary, in the area of the Humber Estuary, and off the Wash in England, and in the Channel.

Dieldrin concentrations in mussels were generally below 2 µg/kg wet weight. Within this low-concentration band, the higher values were found in the Western Scheldt Estuary and in the Ems Estuary.

DDT group

The DDT group includes p,p'DDT, p,p'DDE, and p,p'TDE. Concentrations of the sum of these three compounds (total p,p'DDT) in fish liver (dab and cod) ranged from 5 to 1000 µg/kg wet weight. The highest concentrations were found in cod from the Hardangerfjord on the west coast of Norway influenced by a local source. Very high concentrations were found in cod from the Kattegat; concentrations in cod from other areas on the coast of Norway were relatively low and uniform. Concentrations at the higher end of the range were also found in whiting from the Channel, off the Thames Estuary and, at a lower level, northeast of the Humber Estuary.

In mussels, total DDT concentrations were of the order of 1 to 50 µg/kg wet weight, with the highest values in the Channel, the Western Scheldt Estuary, and at one location in the Sørfjord. Figure 3·10 shows an example of the decreasing trend in concentrations of DDT in mussels from a location near Dunkirk, France, over the period 1979–1990.

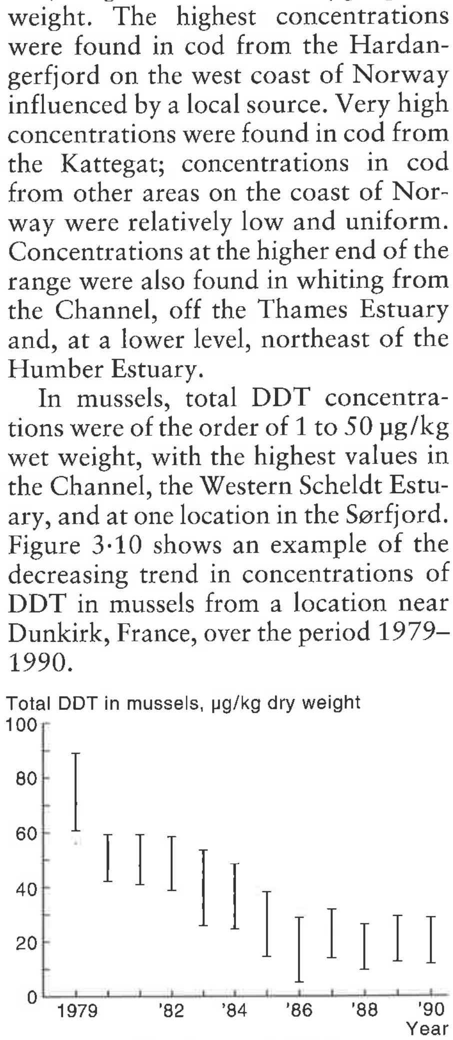


Figure 3·10. Trends in total DDT concentrations (µg/kg dry weight) in mussels near Dunkirk, France.

Radionuclides

Natural radionuclides

Concentrations of radioactivity in biota of the North Sea are predominantly due to natural potassium-40 (Nies *et al.*, 1992). However, some species show high enrichment of polonium (^{210}Po) and lead (^{210}Pb) attributable to releases from the phosphate industry.

Artificial radionuclides

Distributions and concentrations of artificial radionuclides in biota have been the subject of regular studies for many years. Concentrations of most artificial radionuclides show a declining trend, mainly due to reduced discharges from the Sellafield and Cap de la Hague reprocessing plants (Figure 3·11). From 1987 to 1990 there was a general trend of decreasing concentrations of ^{137}Cs in biota sampled along

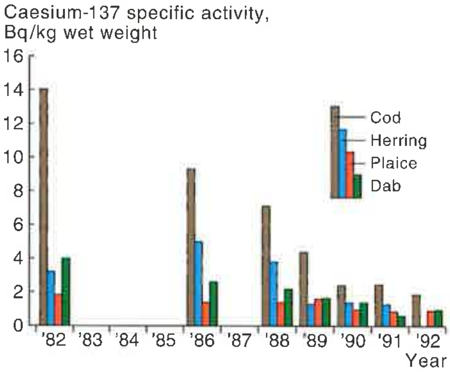


Figure 3·11. Trends in caesium-137 specific activity averaged over the North Sea for different fish species sampled in January of 1982, 1986, and 1988–1992. Source: Kanisch and Nagel (1991).

the east coast of England and Scotland: in 1987 the highest ^{137}Cs concentration determined in cod was 5.2 Bq/kg wet weight and in plaice it was 2.4 Bq/kg wet weight, dropping by 1990 to 1.9 Bq/kg and 0.8 Bq/kg, respectively. The concentrations of the Chernobyl-derived nuclides ^{134}Cs and ^{137}Cs were almost negligible in biota by 1990.

3.3.

Inputs

Introductory note on interpretation

Contaminants enter the North Sea naturally and via rivers and the atmosphere, as well as by direct discharges from land, dumping at sea, discharges from offshore installations, shipping, and aquaculture.

The quantity of contaminants entering the North Sea varies from year to year, and the input is influenced by both natural and anthropogenic processes. Annual riverine input, for instance, can vary greatly as a result of natural variations in river flows.

Since the 1987 *QSR* was published, the Paris Commission has carried out its Comprehensive Study of Riverine Inputs (1990) (OSPARCOM, 1992a). The more intensive geographical coverage and the standardization of methodology have led to better estimates of inputs to estuarine and coastal waters via rivers and direct discharges. There remain, however, problems relating to the sensitivity of the analyses for trace metals and organics. As a result, input loads are quoted as ranges for each determinand, and where these ranges are wide (as in the case of CBs, for example), it is an indication that most of the concentrations were below the limit of detection (not all countries achieved the recommended limits of detection). Previous experience has shown that in such cases the upper estimate tends to be unrealistically high. For riverine and direct inputs the accuracy claimed by some countries was as high as ±20–30% for the 1990 load estimates, which may be an overestimate. The interannual variability due to changes in annual river flows has yet to be assessed. For inputs via dumping the estimated accuracy is ±20–30%, whereas for atmospheric inputs it is ±50–100%. All of these uncertainties must be taken into account when comparing different input sources and assessing trends. An overview of the inputs to the North Sea in 1990 via the various pathways is given in Table 3·16. The relative importance of these input pathways is discussed in greater detail in Chapter 6.

Riverine and direct inputs

This section deals with riverine discharges to estuaries, and direct discharges to estuaries and coastal waters. Riverine inputs comprise those from main rivers, tributary rivers, and coastal areas. Direct inputs are categorized as sewage effluents, sewage sludge, industrial effluents, or polder (land reclaimed from the sea) effluents.

In 1988, the Paris Commission adopted the Principles of the Comprehensive Study on Riverine Inputs. The objective of this study was to assess, as accurately as possible, all riverborne and direct inputs of selected contaminants. Each country was requested to set itself the aim of monitoring 90% of the inputs of each selected contaminant on a regular basis. The results of the input studies will be reviewed periodically with a view to determining temporal trends.

Such a comprehensive study was conducted for the first time in 1990. The following were monitored on a mandatory basis: the metals cadmium, mercury, copper, lead, and zinc; the organohalogen hexachlorocyclohexane; the nutrients nitrate, orthophosphate, total nitrogen, and total phosphorus; and the parameters suspended particulate matter and salinity. It was recommended that the following be monitored on a voluntary basis: polychlorinated biphenyls (CB congeners IUPAC Nos. 28, 52, 101, 118, 138, 153, and 180); other stable organohalogen compounds; and polycyclic aromatic hydrocarbons.

Table 3·5 summarizes information on riverine and direct inputs of metals, organohalogens, and nutrients to the North Sea in 1990. A country-by-country breakdown is given for riverine inputs in Table 3·6 and for direct inputs in Table 3·7.

As required by OSPARCOM in those cases where the results recorded are lower than the detection limit of the analytical method, two load estimates (upper and lower) are shown in the tables. The upper and lower estimates provide maximum and minimum values within which the true estimates fall. The lower estimate is calculated such that any results below the detection limit are considered equal to zero, while for the upper estimate, the value of the detection limit is used.

It must be recognized that it is not yet possible to estimate how much of the riverine and direct loads is retained within estuaries and how much reaches the open sea. Several research projects addressing this issue are being conducted.

Riverine loads of metals and nutrients have both natural and anthropogenic components; furthermore, all riverine inputs include a component derived from long-range atmospheric transport, with the proportion owing to atmospheric deposition depending on the influence of other possible sources in the river catchment areas. In general the proportion is likely to be high for rivers draining the more sparsely populated areas such as northern Norway and Scotland. However, the nature of the land surface of the drainage basin will also influence the proportion of atmospheric input represented in the outflow. It is important to note that the riverine input data reported for Belgium, the Netherlands, and Germany include material discharged in these rivers from other countries.

Table 3·5. Summary of riverine and direct inputs to the North Sea (including the Channel, Kattegat, and Skagerrak) in 1990†. Source of data: OSPARCOM (1992a).

		Cd t	Hg t	Cu t	Pb t	Zn t	γ-HCH kg	CBs¶ kg	NO_3-N kt	PO_4-P kt	Total N kt	Total P kt
Total riverine	Lower estimate*	36.2	21.2	1 220	966	6 340	706	333	645	25.1	901	47.1
	Upper estimate**	42.6	24.8	1 250	996	6 430	869	2 170	652	25.7	912	47.9
Total direct	Lower estimate*	12.8	1.6	285	131	1 260	163	84	21.3	23.2	118	7.1
	Upper estimate**	16.7	1.8	295	157	1 260	191	179	21.4	23.5	120	7.1
Total‡	Lower estimate*	49	23	1 500	1 100	7 600	870	420	670	48	1 000	54
	Upper estimate**	59	27	1 500	1 200	7 700	1 100	2 300	670	49	1 000	55

Table 3·6. Riverine inputs to the North Sea (including the Channel, Kattegat, and Skagerrak) by country in 1990††. Source of data: OSPARCOM (1992a).

	Cd t	Hg t	Cu t	Pb t	Zn t	γ-HCH kg	CBs¶ kg	NO_3-N kt	PO_4-P kt	Total N kt	Total P kt	SPM◊ kt
Belgium	3.2* 4.4**	3.1* 4**	29* 41**	14* 21**	170* 250**	– ca.50**	– ca.20**	16* 23**	1* 1.5**	25* 35**	1.6* 2.4**	340* 700**
Denmark	0.48	0.042	10.5	5.1	75.8	0* 26**	0* 30.3**	51.7	1	59	1.9	n.i.
France	7.9	3.4	170	240	680	n.i.	0.4	88	n.i.	110	8.4	n.i.
Germany§	8.6	10.5	280	210	1 700	340	150	140	3.8	190	11	2 500
Netherlands§	9.5	3.1	380	340	1 900	3.2	150	210	10	330	21	1 700
Norway††	3.2* 3.4**	0.08* 0.19**	126	40* 41**	580	216	1.5* 40**	31	0.4	48	1.1	219
Sweden	< 0.57	0.072	36.7	7.8	226	n.i.	n.i.	21.6	0.23	35.3	1.3	170
United Kingdom	2.7* 7.7**	0.93* 3.5**	187* 202**	109* 131**	1 010* 1 020**	147.1* 234**	30.7* 1 780**	87	8.7* 8.8**	104* 105**	> 0.8	501* 502**
Total‡												
Lower estimate*	36	21	1 200	970	6 300	710	330	640	25	900	47	5 400
Upper estimate**	43	25	1 200	1 000	6 400	870	2 200	650	26	910	48	5 800

Table 3·7. Direct inputs to the North Sea (including the Channel, Kattegat, and Skagerrak) by country in 1990†. Source of data: OSPARCOM (1992a).

	Cd t	Hg t	Cu t	Pb t	Zn t	γ-HCH kg	CBs¶ kg	NO_3-N kt	PO_4-P kt	Total N kt	Total P kt	SPM◊ kt
Belgium	Currently not reported. Direct discharges are deemed to be insignificant compared with inputs via the Scheldt											
Denmark	0.085	0.091	3.13	2.12	7.6	0* 26**	0* 30.3**	2.9	0.34	4.6	0.9	0.2
France	7.7	0.2	9.9	21	33	n.i.	n.i.	n.i.	8.6	1.5	n.i.	750
Germany	< 0.07	< 0.05	< 1.9	< 1	< 5.7	n.i.	< 1	0.04	0.02	0.4	0.05	0.4
Netherlands	< 0.8	< 0.2	19	14	110	13	< 5.9	2.2	1.4	16	3.1	18
Norway†	0.3	0.2	42	11.7	60	n.i.	n.i.	0.009	0.5	10.2	0.8	1 800
Sweden	0.1	0.033	0.48	0.5	7.5	n.i.	n.i.	1.1	0.033	3.7	0.12	3.7
United Kingdom	3.7* 7.6**	0.83* 1**	209* 219**	80.6* 107**	1 040	150* 152**	76.8* 142**	15.1* 15.2**	12.3* 12.6**	81.3* 83.3**	2.1	810
Total‡												
Lower estimate*	13	1.6	280	130	1 300	160	84	21	23	118	7.1	3 400
Upper estimate**	17	1.8	290	160	1 300	190	180	21	23	120	7.1	3 400

† using 1991 data on inputs from Norway;
†† using 1991 data on inputs from Norway; in 1990 detection limits for Cd, Cu, and Pb were too high, which may have resulted in overestimation of loads, thus, 1991 data are used;
§ including loads from countries upstream;
‡ total rounded to two significant figures;
* 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;
¶ IUPAC CB Nos. 28, 52, 101, 118, 138, 153, 180;
◊ suspended particulate matter;
n.i.: no information.

Much of the anthropogenic contribution from land-based sources is discharged via waste-water treatment systems; accordingly, an increasing trend in the use of such systems can give a general indication of decreasing levels of inputs. However, between 1985 and the late 1980s, in most countries there was only a slight increase in the application of more advanced waste-water treatment. As a result it may be expected that reductions in inputs from this source will be seen to be marginal over this period.

Apart from the OSPARCOM input surveys, information on trends in riverine inputs is limited to a few national studies cited in the subregional assessment reports. On the basis of these reports:

- it is estimated that between the 1930s and 1985 the input of phosphorus from the Rhine/Meuse increased by a factor of approximately 10. Between 1985 and 1990 a clear reduction took place in riverine inputs of phosphorus. The reduction in the input of nitrogen over the same period is less pronounced;
- there are indications of a gradual decrease in phosphorus inputs to the Wadden Sea. It is unclear whether nitrogen loads are indeed decreasing or whether the reductions occasionally observed during the last few years have been caused by very low river flows;
- inputs of metals from the English east coast have decreased. The overall inputs decreased considerably over the period 1975–1990, although the earlier data are less reliable than those for 1990;
- with the exception of zinc, inputs of heavy metals to the Channel decreased substantially over the period 1975–1990. The same is true of total nitrogen. However, part of this apparent improvement may be due to changes in analytical methods;
- inputs of cadmium and mercury from the Rhine/Meuse decreased by ca. 90% and 75%, respectively, during the period 1980–1990, but most of this reduction took place prior to 1985. The input of cadmium from the Western Scheldt decreased by ca. 80% between 1985 and 1990;
- there appears to have been a decrease in riverine loads of the heavy metals mercury, cadmium, and lead, and a number of chlorinated hydrocarbons from the Elbe between 1988 and 1991. The extent to which this apparent reduction is attributable to improvements in analytical methods or to very low river flows is uncertain at present;

Table 3·8. Estimates of atmospheric inputs to the North Sea* in 1990, based on deposition measurements at coastal stations and calculated for an area of 525 000 km². Source of data: OSPARCOM (1992a).

Range	Cd t	Hg t	As t	Cr t	Cu t	Ni t	Pb t	Zn t	γ-HCH t	α-HCH t	N kt
Minimum(rounded)	32	3.3	95	88	320	180	960	2700	5.3	0.6	330
Maximum(rounded)	74	6.9	220	180	740	400	1700	5500	8.1	1	520

*estimated inputs cover the North Sea to 59°N, including the Kattegat and Skagerrak, but not the Channel. Figures for Cr and HCH are unreliable and should therefore be used with caution.

- annual inputs of cadmium, mercury, copper, lead, zinc, HCH, and PCBs from the Dutch IJsselmeer to the Wadden Sea during the period 1983–1991 do not show a decreasing trend. Any trends may, however, be obscured by changes in analytical methods.

Atmospheric inputs

The estimates given for atmospheric inputs to the North Sea are based on studies by the Working Group on Atmospheric Inputs of the Paris Commission (ATMOS).

Three approaches are used to estimate atmospheric inputs to the North Sea:

1) a mean value is calculated from actual deposition measurements at coastal stations;
2) a mean value is calculated on the basis of a weighted mean concentration at coastal stations and an estimated precipitation input to the North Sea;
3) estimates are made using models employing emission data.

According to ATMOS, a factor-of-two difference between measurement results and modelled results is considered acceptable. All three approaches used to estimate atmospheric inputs provide results with roughly equivalent levels of uncertainty: the method of extrapolating measurements at coastal stations is crude and can result in an overestimation of inputs to the open sea; and computer models are dependent on accurate information on emission values and an understanding of deposition mechanisms, both of which are still subject to uncertainties. Atmospheric input data presented here must therefore be used with great care.

There are no compiled data available from OSPARCOM concerning atmospheric inputs of CBs, PAHs, and most hydrocarbon insecticides. However, deposition of some of these compounds may be an important input to the North Sea; e.g., it is estimated that 130 kg/year of total CBs are deposited from the atmosphere in Subregion 6.

Table 3·8 shows the estimated atmospheric inputs of different metals (cadmium, mercury, arsenic, chromium, copper, nickel, lead, zinc), nitrogen, and two isomers of hexachlorocyclohexane (α-HCH, γ-HCH) to the North Sea in 1990. The minimum and maximum values given indicate the range of available input estimates. According to ATMOS, the deposition data for chromium and HCH are, however, not reliable and should be used with caution and not be considered quantitative deposition estimates at this stage.

For cadmium, copper, lead, zinc, and nitrogen, both the minimum and the maximum values of the estimates for 1990 are lower than those for 1988 presented in the 1990 *QSR*; for lead and copper the 1990 estimates are lower by a factor of two. Earlier estimates for the other compounds were not available. However, with the probable exception of lead, this decrease cannot be realistically regarded as a trend, but rather as a result of improvements in the methods used to calculate inputs. For lead a reliable estimate of a decreasing trend of 40–50% over the period 1986–1990 could be made on the basis of weekly sampling at Helgoland in Subregion 5.

Incineration and dumping

This section concerns the deliberate thermal destruction of waste at sea (incineration) and the deliberate disposal of waste and other matter in the sea (dumping). It is based on work done under the Oslo Convention.

Incineration

The quantities of waste incinerated at sea during the period 1981–1991 are shown in Figure 3·12.

The amount incinerated fluctuated around 100 000 tonnes per year from 1981 to 1988, after which it fell sharply, decreasing by 65% between 1987 and 1990. Table 3·9 shows the amount incinerated in 1990 and the estimated associated emissions of metals and organohalogens. Incineration of waste at sea was terminated by 1 February 1991.

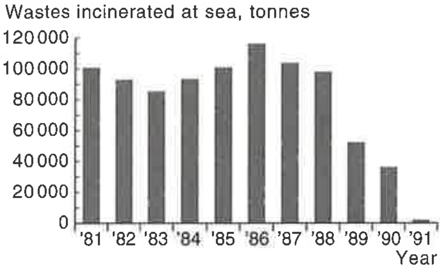


Figure 3·12. Quantities of waste incinerated at sea, 1981–1991. Source of data: OSPARCOM. Incineration at sea ceased in February 1991.

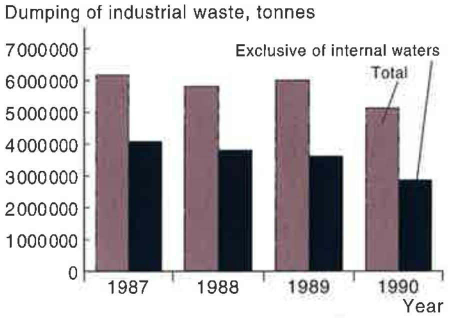


Figure 3·13. Dumping of industrial waste 1987–1990. Source of data: OSPARCOM.

Dumping

The quantities of waste dumped into the North Sea in 1990 are summarized in Table 3·10. The wastes are divided into three categories: industrial waste, sewage sludge, and dredged material. In addition to these categories, about 300 tonnes of concrete, scrap iron, and cable and wire, as well as 36 wooden and steel ships, were dumped by Norway in its internal waters.

Industrial waste

This category covers a variety of waste types, such as waste from the production of titanium dioxide, phosphogypsum waste from the production of fertilizers, brine from alkylated intermediates, acid ammonium sulphate from methyl methacrylate manufacture, colliery waste, fly ash, rock, tailings, fish offal, and sediments.

Figure 3·13 shows the development of dumping of industrial waste during the period 1987–1990. The amounts dumped in the North Sea decreased from about 4.1 (6.1) million tonnes in 1987 to about 2.8 (5.0) million tonnes in 1990. Figures in brackets represent amounts that include dumping in internal waters. An important step towards the reduction and termination of dumping of industrial waste was taken in April 1987, when France ceased its dumping of phosphogypsum. A further sharp reduction occurred in 1989/1990 after Belgium and Germany phased out the dumping of waste from the production of titanium dioxide by the end of 1989. Additional reduction took place in the quantities of industrial waste dumped as the United Kingdom completed its phase-out of liquid industrial waste disposal at sea. Disposal of colliery waste has continued, since this material falls under the exemption in OSCOM's Decision 89/1, concerning inert material of natural origin.

Table 3·11 shows the quantity of industrial waste dumped in the North Sea by the United Kingdom in 1990 and the associated metal load.

Table 3·9. Incineration of waste at sea in 1990. Quantity incinerated and estimated emissions of organohalogens and metals. Source of data: OSPARCOM (1992b). Incineration at sea ceased in February 1991.

	Quantity incinerated, t	Organo-halogens, t	Metals, kg Cd	Hg	As	Cr	Cu	Ni	Pb	Zn
Belgium	6 028	0.3	3.7	0.6	0.5	10	7.2	17	9.1	55
France	16 720	0.2	12	1.9	1.8	252	n.i.	428	337	1 105
Spain	9 051	0.3	45	45	45	4 530	4 530	4 530	4 530	4 530
United Kingdom	4 231	0.01	2.2	0.2	n.i.	106	27	28	7.9	31
Total*	36 030	0.8	63	48	47	4 900	4 600	5 000	4 900	5 700

* total emissions rounded. Emissions are order of magnitude only, owing to incomplete data and different methods of calculation;
n.i.: no information.

Table 3·10. Quantities of waste (t) dumped in the North Sea (including the Channel, Kattegat, and Skagerrak) in 1990. Source of data: OSPARCOM (1992b).

	Waste category	Amount dumped, t
United Kingdom	Industrial waste*	5 012 319 (including 2 182 128 t dumped in internal waters)
United Kingdom	Sewage sludge	5 377 157
Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, and United Kingdom	Dredged material (from harbours, estuaries, and sea)	136 037 942 (including 71 251 720 t dumped in internal waters)

* chemical waste, fly ash, and 'inert material of natural origin' (rock, tailings, sediments).

Table 3·11. Industrial waste (t) dumped in the North Sea by the United Kingdom in 1990. Source of data: OSPARCOM (1992b).

	Amount dumped, t	Contaminant load, t ‡ Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCBs
Inert materials*	4 534 649†	0.24	0.16	n.i.	21	180	64	210	430	n.i.
Industrial waste**	477 670	0.07	0.05	2.4	2.8	6	0.7	11	7	n.i.
Total	5 012 319†	0.3	0.2	n.i.	24	180	64	220	440	n.i.

*inert materials of natural origin (minestones and colliery tailings);
**chemical wastes, slurries, including fly ash. Dumping of this material was terminated at the end of 1992;
† including 2 182 128 tonnes dumped in internal waters;
‡ loads are rounded. Metal loads from dumping of inert materials are minimum values as loads are not determined for materials dumped in internal waters;
n.i.: no information.

Sewage sludge

The only country that continues to dump sewage sludge in the North Sea is the United Kingdom. During the period 1987 to 1990, the quantity of sewage sludge dumped was about 5.1 to 5.7 million tonnes annually. Table 3·12 shows the amount dumped in 1990 and its associated metal and nutrient (N, P) load. According to OSCOM Decision 90/1, the dumping of sewage sludge will be terminated by the end of 1998 at the latest.

Dredged material

Sediments may be dredged in harbour areas, estuaries, and navigation channels. Dredging is necessary, for example, to maintain the required navigable depth in shipping lanes. The quantities of dredged material vary from year to year and depend on patterns of sediment movement and accretion that make recurrent maintenance dredging necessary, as well as on new projects for port and harbour development requiring capital dredging.

The load of contaminants deposited with dredged material in the marine environment is considerable. The deposition of material arising from capital dredging and maintenance dredging in open sea areas can be viewed simply as a relocation of material rather than a new input. In the case of material removed by capital dredging, the contaminant burden will be predominantly of natural origin. However, sediments in enclosed harbour basins and estuaries derived principally from riverine sources may contain a significant anthropogenic contaminant load and should be considered as a source of inputs.

Table 3·13 summarizes available information on the dumping of dredged material in offshore waters in 1990; it also includes information from some countries on dumping in internal waters. The total amount dumped in the North Sea amounts to about 136 million tonnes; of this about 71 million tonnes were dumped in internal waters. The total metal load, which is made up of a natural geological background component as well as a quantity from anthropogenic contamination, is considerable. The anthropogenic fraction is not easily estimated, nor are

Table 3·12. Sewage sludge (wet tonnes) dumped in the North Sea (including the Channel) by the United Kingdom in 1990. Source of data: OSPARCOM (1992b).

	Amount dumped, t	Contaminant load, t Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCBs	N	P
Total*	5 377 157	1.2	0.7	0.1	21	76	11	77	160	n.i.	6 300	570

*contaminant figures are rounded; n.i.: no information.

Table 3·13. Dredged material and associated contaminant loads (t) dumped in the North Sea (including the Channel, Kattegat, and Skagerrak) in 1990. Source of data: OSPARCOM (1992b).

	Amount dumped, t	Contaminant load, t Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCBs
Harbour areas*	64 546 834	29.1	10.0	440	1 770	927	621	1 770	5 000	0.4
Estuaries and navigation channels*	71 491 108	41.4	8.7	279	1 040	398	584	971	2 900	0.2
Total* †	136 037 942	71	19	720	2 800	1 300	1 200	2 700	7 900	0.6

* including dumping in internal waters; † total contaminant loads rounded to two significant figures.

Table 3·14. Dredged material and associated contaminant loads (t) from harbour areas, dumped in the North Sea (including the Channel, Kattegat, and Skagerrak) in 1990. Source of data: OSPARCOM (1992b).

	Amount dumped, t	Contaminant load, t Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCBs
Belgium	5 018 340	13.4	1.87	69.2	224	150	114	351	788	0.07
Internal waters	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Denmark	578 635	0.11	0.03	1.0	2.3	1.3	1.3	2.0	9.8	n.i.
Internal waters	324 360	0.06	0.03	0.7	5.2	3.4	1.2	4.7	21.3	0.000 02
France	6 264 062	2.53	<0.66	34.1	188	61.2	51.1	171	531	<0.09
Internal waters	24 180	<0.005	0.002	0.1	0.3	n.i.	0.1	0.2	1.8	0
Germany	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	3 960 530	<2.78	1.11	19.4	167	40.6	48.6	117	305	<0.02
Netherlands	20 224 764	6.00	2.40	95.3	410	165	130	325	1180	0.18
Internal waters	9 104 415	1.00	0.55	21.5	77.6	28.7	29.2	69.2	226	0.02
Norway	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	179 335	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Sweden	130 000	0.07	0.01	n.i.	n.i.	0	n.i.	0	n.i.	n.i.
Internal waters	122 830	0.03	0.03	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	0.01
United Kingdom	4 271 759	0.75	0.72	1.0	115	123	46.4	148	292	n.i.
Internal waters	14 343 624	2.44	2.64	198	578	354	199	579	1 640	n.i.
Total*	36 487 560	22.9	5.7	201	939	500	343	997	2 800	0.3
Total**	64 546 834	29.1	10.0	440	1 770	927	621	1 770	5 000	0.4

* excluding dumping in internal waters; ** including dumping in internal waters;
n.i.: no information; n.a.: not applicable.

Table 3·15. Dredged material and associated contaminant loads (t) from estuaries and navigation channels, dumped in the North Sea (including the Channel, Kattegat, and Skagerrak) in 1990. Source of data: OSPARCOM (1992b).

	Amount dumped, t	Contaminant load, t								
		Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCBs
Belgium	18 428 951	34.1	5.34	197	540	189	334	589	1 550	0.12
Internal waters	9 364 287	3.43	0.78	30	81.4	5.2	114	47.1	504	0.01
Denmark	2 529 000	0.22	0.11	n.i.	19.6	12.5	n.i.	19.8	76.0	n.i.
Internal waters	112 020	0.002	0.0004	0.01	0.1	0.1	0.2	0.1	0.7	n.i.
France	4 264 028	0.20	0.04	2.3	6.9	2.8	2.3	5.5	18.9	0.005
Internal waters	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Germany	44 000	0.04	0.01	n.i.	1.2	0.4	0.5	1.2	3.5	n.i.
Internal waters	29 789 000	2.42	1.63	49.3	280	55.0	90.4	153	444	0.08
Netherlands	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internal waters	3 582 136	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Norway	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.
Sweden	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.
United Kingdom	3 032 683	0.95	0.70	0.5	98.8	130	38.3	153	290	n.i.
Internal waters	345 003	0.04	0.08	0.03	8.0	2.6	4.2	2.4	13.0	n.i.
Total*	28 298 662	35.5	6.2	200	666	335	375	768	1 940	0.1
Total**	71 491 108	41.4	8.7	279	1 040	398	584	971	2 900	0.2

*excluding dumping in internal waters; ** including dumping in internal waters; n.i.: no information; n.a.: not applicable.

Table 3·16. Estimates of inputs (t) to the North Sea (including the Channel, Kattegat, and Skagerrak, except for atmospheric inputs*) via various pathways in 1990. Source of data: OSPARCOM (1992a); OSPARCOM (1992b).

Pathway	Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	CBs	HCH	N	P
Riverine inputs†	43	25	n.i.	n.i.	1200	n.i.	1000	6400	2.2	0.9◊	910 000	48 000
Direct inputs†	17	1.8	n.i.	n.i.	290	n.i.	160	1300	0.2	0.2◊	120 000	7 100
Atmosphere*†‡	74	6.9	220	[180]	740	400	1700	5500	n.i.	[9.1]•	520 000	n.i.
Disposal at sea												
Incineration	0.1	0.05	0.05	4.9	4.6	5.0	4.9	5.7	n.i.	n.i.	n.i.	n.i.
Industrial waste **	0.3	0.2	n.i.	24	180	64	220	440	n.i.	n.i.	n.i.	n.i.
Sewage sludge	1.2	0.7	0.1	21	76	11	77	160	n.i.	n.i.	6 300	570
Dredged material¶	71	19	720	2 800	1 300	1 200	2 700	7 900	0.6	n.i.	n.i.	n.i.

* estimates of atmospheric inputs cover the North Sea to 59°N, including the Kattegat and Skagerrak, but not the Channel;
† maximum (upper) estimates;
‡ based on deposition measurements at coastal stations (calculated for an area of 525 000 km^2);
**chemical waste, slurries, fly ash, minestones and colliery tailings. Metal loads are minimum values as loads are not determined for inert materials dumped in internal waters;
¶ dredged materials from harbours, estuaries, and navigation channels; including dumping in internal waters;
◊ γ-HCH; • γ-HCH (8.1 t) + α-HCH (1 t);
n.i.: no information; [ ]: not reliable.

the availability of trace metals in both natural and anthropogenic components and their subsequent biological significance clearly understood.

Tables 3·14 and 3·15 present data on the dumping of dredged material from harbour areas, and from estuaries and navigation channels, respectively, on a country-by-country basis in 1990. In response to measures adopted by the North Sea States to reduce inputs to the North Sea, the anthropogenic contaminant load of dredged material is expected to decrease in future.

Table 3·16 summarizes the estimates of inputs of various contaminants to the North Sea in 1990 according to input pathway (rivers, direct discharges, the atmosphere, or disposal of waste at sea).

Radioactive substances

Nuclear industry

The main sources of inputs of artificial radionuclides to the North Sea are discharges from nuclear reprocessing plants, nuclear fuel fabrication, and, to a lesser extent, nuclear power stations. Inputs can be divided into direct inputs, inputs via rivers (particularly the Rhine and the Thames), and inputs via adjacent waters. With the exception of tritium, not all radionuclides discharged into rivers or adjacent waters necessarily reach the North Sea.

A detailed overview of radioactive discharges was published recently by the Oslo and Paris Commissions (OSPARCOM, 1992d). From this report the following conclusions can be drawn:

- the main direct source is the discharge from the Cap de la Hague reprocessing plant into the Channel, which shows a decrease in most radionuclides since 1985;
- an important source of artificial nuclides is the Sellafield reprocessing plant on the west coast of England, via inflow of Atlantic water, with additional smaller contributions from Dounreay. Discharges from Sellafield, other than tritium, had decreased to less than 3% of their 1983 level by 1992;
- inputs of tritium via rivers increased by approximately 70% between 1985 and 1990 mainly owing to an increase in the capacity of nuclear power stations along the rivers Rhine, Meuse, Scheldt, and Elbe. However, inputs of other radionuclides via rivers were reduced considerably over this period.

Other sources

The primary sources of natural radionuclides are natural processes of weathering and transport. Inputs of natural radionuclides other than from the nuclear industry also arise from emissions of the phosphate-ore processing industry; however, a complete overview of this source is lacking. Total input from the Belgian/Dutch coast amounts to about 1300 MBq per year of polonium-210 and about 1100 MBq per year of lead-210 and radium-226.

Offshore oil and gas industry

Since the late 1960s when oil and gas exploration and production in the North Sea started, a large number of wells have been drilled, using diesel-based drilling muds (up to 1985), (low aromatic) oil-based muds, and water-based muds. Figure 1·10 shows the geographical extent of the offshore oil and gas drilling activities over the last 30 years. The map shows the existence of relatively dense drilling activity in the central North Sea (area between northeast United Kingdom and southwest Norway) and in the southern North Sea (the United Kingdom and Dutch sectors).

Sources of contaminants arising from the offshore oil and gas industry are:

- drilling muds and cuttings from the use of water-based muds;
- cuttings containing oil from the use of oil-based muds;
- production water;
- spills and flaring.

A major component of these sources is oil, but other substances are also involved.

Figure 3·14 shows the quantities of oil discharged with cuttings, production water, and accidental spills from 1984 to 1990. The total amount of oil discharged shows no real trend over this period. Fluctuations merely reflect responses to economic factors. The amount of oil discharged via cuttings is by far the largest source.

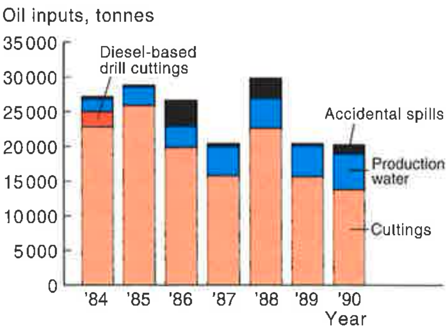


Figure 3·14. Total quantities of oil discharged by the offshore industry via cuttings, production water, and accidental spills, 1984–1990. Oil-based drilling muds formulated using diesel oil were not used after 1984. Source of data: OSPARCOM.

Box 3·8. *Chemicals used in offshore oil and gas exploration and exploitation*

The components of oil- and water-based drilling muds are numerous, including barite with variable amounts of toxic heavy metals, bentonite, inorganic salts, surfactants, a variety of organic polymers, detergents, corrosion inhibitors, biocides, and lubricants in the form of oil-in-water (oil-based mud) or water emulsions (water-based mud). The chemical composition and amount used in any mud system depend on factors such as the type of rock being drilled, the depth of the well, and the angle of deviation. Chemicals are also used during oil and gas production and in pipeline protection.

Some of the chemicals used are totally discharged (e.g., water-based mud), and others are partially discharged (e.g., according to their partition between the oil and water phases during separation processes and the discharge of production water). Some of the chemicals are intended to remain down well or to be transported to shore with the oil, or to adhere to pipelines to protect them, although it is likely that a proportion of these chemicals will also be discharged.

Production water is a very complex oil and chemical mixture and will vary in composition not only from field to field but also within one field depending upon its duration of operation. The amount of production water discharged per year has increased during recent years, as has the amount of oil discharged with production water. In addition to dissolved hydrocarbons derived from crude oil, production water also contains substantial amounts of organic matter largely as salts of acetic, propionic, and butyric acids (Box 3·8). At peak production it has been estimated that for the United Kingdom sector alone, this will contribute 10 000 to 20 000 tonnes of organic acids each year (Hurford *et al.*, 1989).

With some exceptions (as in 1986, 1988, and 1990), accidental spills result in relatively minor amounts of oil entering the North Sea. The possible contribution of flaring to oil contamination has not been quantified; however, recent Danish observations have shown that, owing to incomplete combustion, flaring may lead to visible oil contamination (indicating a concentration of at least 40 mg/l oil at the water surface).

Data on the quantities of other chemicals discharged during offshore activities are very limited. Table 3·17 shows the discharges of some of the priority substances used offshore in 1991 by Denmark, the Netherlands, and the United Kingdom. Information from Norway is not available. Table 3·18 shows the total discharges of production, utility, and drilling chemicals from offshore installations in the Danish, Dutch, Norwegian, and United Kingdom sectors in 1991, based upon information gathered within the framework of the Paris Commission's Oil Pollution Working Group. It should be noted that the main sources of heavy metals are the barite and bentonite minerals used in drilling muds.

Table 3·17. Discharges of priority substances (kg) via chemicals used in offshore oil and gas production in 1991. Source: OSPARCOM (in preparation).

Substance	Quantity discharged kg
Cadmium (and compounds)	3 751
Mercury (and compounds)	1 046
Organophosphorus compounds	5 905
Persistent synthetic compounds	12 427
Zinc	85 146
Lead	12 319
Chromium	18 628
Nickel	14 962
Copper	39 846

Figures show discharges by Denmark, the Netherlands (preliminary), and the United Kingdom; information from Norway is not available.

Table 3·18. Total discharges (t) of production, utility, and drilling chemicals from oil and gas production facilities in 1991. Source: OSPARCOM (in preparation).

Substance/use	Total quantity discharged t
Antifoam (hydrocarbons)	10
Asphalts and asphalt-based products	319
Biocides	382
Carrier solvents	658
Coagulants/deoilers	119
Corrosion inhibitors	828
Cutting wash fluids	219
Defoamers	146
Demulsifiers	155
Detergents/cleaning fluids	891
Dispersants	468
Drilling lubricants	261
Dyes	32
Emulsifiers	826
Flocculants (water injection)	79
Fluid-loss control agents	1 159
Gas treatment chemicals	2 225
Gels	6 348
Inorganic chemicals	32 095
Lignosulphonates/lignites	651
Lost circulation materials	2 175
Oxygen scavengers	206
Pipe release agents	39
Polymeric viscosifiers and filtrate reducers	7 122
Scale inhibitors	4 369
Scale inhibitors/encapsulators	3 990
Surfactants/detergents	376
Thinners	625
Viscosifiers	3 936
Weighting agents and inorganic gelling products	313 384
Water-based muds and additives	202

Discharges of ballast water from tankers and other operational discharges are made from the oil terminals in the United Kingdom such as Sullom Voe in the Shetland Islands, which receives the major flow of oil from the North Sea to the United Kingdom. Reductions have been made in the amount of oil discharged from terminals since 1985, and between 1990 and 1991 reductions from terminals and refineries in Norway were achieved (Mannvik *et al.*, 1990).

Shipping

It has proved extremely difficult to gather full information on the scale of discharges from shipping. Such discharges fall into two categories: accidental and operational (legal and illegal). Control of operational discharges falls within the mandate of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78).

Tank washings from chemical tankers carrying the most hazardous substances must be discharged at on-shore reception facilities. Washings from tanks that have been used to transport less hazardous substances may be discharged at sea, but the quantities and concentrations of the chemicals in the washings are controlled. Surveys of United Kingdom east coast ports conducted in 1986 and 1988 included analysis for a range of target compounds identified on the basis of lists of chemicals transported in the North Sea, and only very low concentrations were detected.

The quantity of oil entering the sea from accidents varies enormously from one year to another. Legal operational discharges of oil from shipping are estimated at 1000 to 2000 tonnes per year, roughly 0.5–2% of the total input to the North Sea (Table 3·19). On the basis of investigations it was concluded that legal operational discharges cannot usually be detected either by eye or by remote-sensing techniques, and they are not likely to present problems since the oil discharged is dissolved or dispersed in water and amenable to further dispersion and degradation processes.

Illegal operational discharges can usually be detected. Results obtained from observations made during regular national and international aerial surveillance flights in 1990 and 1991 are summarized in Figure 3·15. While some slicks occur close to offshore installations, the majority of sightings are confined to the major shipping corridor between the Strait of Dover and the German Bight. Extrapolation from airborne surveillance observations to quantitative estimates of oil inputs from illegal operational discharges is not straightforward. The estimated volume of oil in slicks detected annually from 1986 to 1991 varied from about 700 to 2400 m^3 (up to ca. 2000 tonnes of oil). These estimates may be likened to a series of snapshots at the times of observation, and they do not represent the totality of the slicks (for an estimate of the total see Table 3·19). Discharges of oil from shipping certainly occur with great regularity and, at least in terms of the number of incidents, they are significant. Regular aerial surveys of the Dutch and German continental shelf have been carried out since 1983. Over the period 1985–1990 no trend was apparent in the number of oil slicks observed on the Dutch continental shelf.

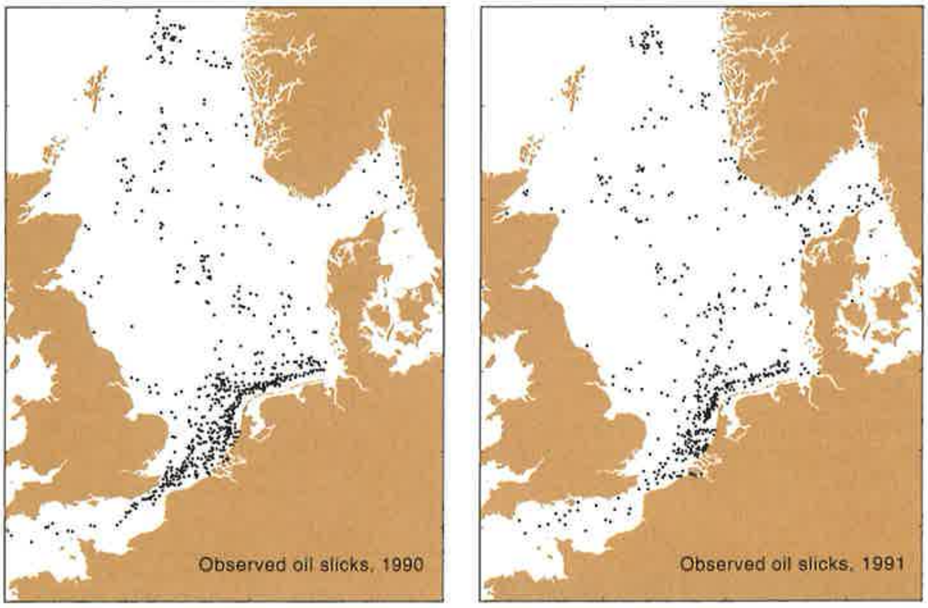


Figure 3·15. Oil slicks detected visually and by remote sensing during aerial surveillance flights made in 1990 and 1991 under the Bonn Agreement. During both years most slicks were observed in the shipping corridor between the Strait of Dover and the German Bight.

Table 3·19. Total oil input (10^3 t/year) to the North Sea.

Source	Input 10^3 t/year
Natural seeps	1
Atmosphere	7– 15
Rivers/land run-off	16– 46
Coastal sewage	3– 15
Coastal refineries	4
Oil terminals and reception facilities	1
Other coastal industrial effluents	5– 15
Offshore oil and gas production	29*
Sewage sludge	1– 10
Dumped industrial waste	1– 2
Dredged spoils	2– 10
Operational ship discharges	1– 2
Accidental or illegal discharges from shipping	15– 60**
Total	86–210

* 20–30 $\times 10^3$ t/year over the period 1984–1990 (PARCOM estimates);
**from subregional assessment report for Subregion 4.

Inputs to the North Sea from aquaculture

The cultivation of fish in coastal waters leads to a direct input of nutrients and other chemicals (e.g., therapeutants) to the sea. Shellfish cultivation does not normally involve the addition of material such as feed, etc., to the sea and therefore does not constitute a new source of these substances. The estimated annual inputs of nutrients from mariculture are 1400 tonnes of total nitrogen and 180 tonnes of total phosphorus for Shetland fish farming, 3900 tonnes N and 500 tonnes P for Norwegian, and 4.6 tonnes N and 0.9 tonnes P for Danish fish farming. These inputs are small in relation to the natural flux of nutrients through the area via water movement. However, local effects have been observed, and in extreme cases, nutrient inputs in the immediate vicinity of finfish aquaculture facilities can exceed those from natural sources.

Antibacterial agents are used in fish farming to control infections. The main compounds licensed for this purpose include oxytetracycline, oxolinic acid, and tribrissen. The total amount of antibacterial agents used in Norwegian mariculture in 1991 was 26.8 tonnes. Approximately one third of the Norwegian farmed-fish production is located in Subregion 6. It should be noted that production volumes do not always reflect the use of such agents. No data are available for Shetland.

An organophosphorus compound, dichlorvos, or its chemical precursor, is used to control sea lice infestations in salmon farming, and this is normally released in the sea. In 1990 the use of 1.9 tonnes was reported in Shetland, and 3.42 tonnes (plus about 2.3 tonnes of precursor) in Norwegian aquaculture.

A variety of other substances are used which are also released in the environment. Data are only available for Norwegian aquaculture as a whole, and they include for the year 1990: 135 tonnes of copper (in anti-fouling agents) and 25 tonnes of formaldehyde (as disinfectant or therapeutant). Data for Shetland are not available.

3.4.

Nutrients and oxygen

General aspects

The production of phytoplankton in the sea depends on light and nutrients. Net growth of phytoplankton takes place within the water column to a depth where light irradiance is approximately 1% of the irradiance just under the water surface. Depths may range from less than 10 cm in turbid coastal waters to more than 30 m in clear offshore water. In much of the North Sea the nutrients in the upper water layer are depleted as a result of phytoplankton growth during summer after the water column becomes stratified through warming. Mixing brings nutrients up from deeper water and from the sediments. During autumn and winter when mixing is intense and the light conditions poor, nutrients accumulate in surface water and reach maximum concentrations in late winter (Box 3·9). In addition to processes of remineralization, which release nutrients, and vertical mixing, nutrients are also supplied to the coastal zone in discharges from rivers, sewage effluents, certain types of industry, and more generally from atmospheric inputs. Silicate is typically the first nutrient to become depleted from the coastal water mass of the southern North Sea in spring.

Phytoplankton production, or primary production, releases oxygen from the CO_2 that is fixed and transformed by energy from light into organic matter. When organic matter is consumed by animals or broken down by bacteria and other micro-organisms, the oxygen is utilized. Decomposition of organic matter stemming from activity in the productive upper water layer can lead to a decrease in the oxygen content of the water layer below. When water is stratified, this may result in oxygen deficiency in the deeper layer. Stimulated production due to extra inputs of nutrients will lead to increased oxygen consumption. Oxygen deficiency is most likely to occur in bottom waters under stratified conditions where the rate of replenishment or exchange of bottom water is slow and the oxygen demand is sufficiently high, e.g., in fjords with shallow sills and the German Bight and on the Oyster Ground (Figure 5·1). Oxygen deficiency is not a problem in the deep Skagerrak, where a large volume of water provides adequate oxygen during the decomposition process.

Box 3·9. *The role of nutrients in algal production*

Nutrients comprise a range of elements and compounds that are essential for plant growth. The three most important of these are nitrogen compounds, phosphorus compounds, and silicates. They are naturally present in sea water as inorganic nutrient salts that are taken up and converted into phytoplankton biomass. Phytoplankton is eaten by zooplankton, which is eaten by fish and other fauna in the marine food webs (See Chapter 4). At each step in the food chain, some of the nitrogen and phosphorus is excreted back into the water as dissolved nutrients (both inorganic and organic). Here they can again be used by phytoplankton in a new cycle of production. The third major nutrient, silicate, is required by an important group of algae, the diatoms, which have silicified shells. Silicate is more slowly recycled by dissolution of dead diatoms.

In winter, phytoplankton production is limited by low temperatures, poor light conditions, and mixing by wind. At this time, nutrients build up in the water through increased river discharge and reduced fixation in riverine source waters, while remineralization of biological material continues at sea. In spring, with improved light conditions, reduced wind mixing, and increased riverine input, the nutrients are utilized by the phytoplankton bloom. The spring bloom is usually terminated by nutrient depletion, and the biomass during the summer is typically lower and fueled largely by excreted nutrients from the food chain and, in the coastal zone, sustained by riverine input.

Nitrogen occurs in various inorganic and organic forms. Nitrogen accumulated over the winter and in deeper water is mainly in the form of nitrate. Bacteria and animals release nitrogen in the form of ammonia or as various organic compounds such as urea. Algal production based on nitrate is called new production, whereas production based on ammonia and organic nitrogen released from the food chain is called regenerated production. The latter is basically a closed cycle, and it is the new production that forms the basis of large fisheries in areas with extensive winter mixing, such as the North Sea, or where deepwater upwelling occurs. Phosphorus also occurs in inorganic and organic forms. The inorganic chemical form is orthophosphate, whereas there are numerous compounds of organically bound phosphorus.

Nutrient concentrations

Spatial distribution

Typical winter nutrient concentrations in Atlantic water entering the North Sea from the north are: 12 µmol/l nitrate, 0.8 µmol/l inorganic phosphate, and 6 µmol/l silicate. These values can be considered the background concentrations for Atlantic water. Somewhat higher concentrations can be found in deeper stagnant water layers, and much higher values are found in coastal waters influenced by rivers. Lower winter values are normally found in offshore areas of the North Sea.

Concentrations of nitrate in major rivers that discharge into the southern North Sea are about 50 times higher than the background nitrate concentration in Atlantic water. The conventional way of representing the mixing of river water and sea water is to plot the concentration of the substance of interest against salinity. Such mixing diagrams for nitrate and phosphate for various rivers and estuaries are shown in Figure 3·16. Nitrate concentrations close to the river mouth (at zero salinity) range from 350 to more than 600 µmol/l. The mixing diagram for nitrate shows linear relationships with salinity for salinities higher than 8, which demonstrates that dilution through mixing is the main process governing the nitrate concentration in estuaries during winter. For phosphate this is less clear, owing to the strong interaction of PO_4^{3-} with flocculation processes and particulate matter during initial estuarine mixing.

The mixing diagram for nitrate shows how the influence of the river nitrate decreases on nearing the salinity corresponding to Atlantic water entering the northern North Sea (approximately 35). Nitrate concentrations are still markedly elevated at a salinity of 33 with values between 20 and 50 µmol/l (Figure 3·16). At salinity 33 the river water has been diluted 18 times if mixed with sea water with a salinity of 35. The expected nitrate concentration from the river source (350–600 µmol/l) would then be 20 to 35 µmol/l, which is in good agreement with the concentrations observed. Thus, using a salinity of 33 as a reference, at least during winter months and prior to the spring bloom utilization of nutrients, there is a clear and substantial increase in nitrate by a factor of 2 or more above the Atlantic water background concentration due to riverine input.

Patterns of spatial distribution of nutrients in the winter reflect the major sources of inputs to the North Sea from

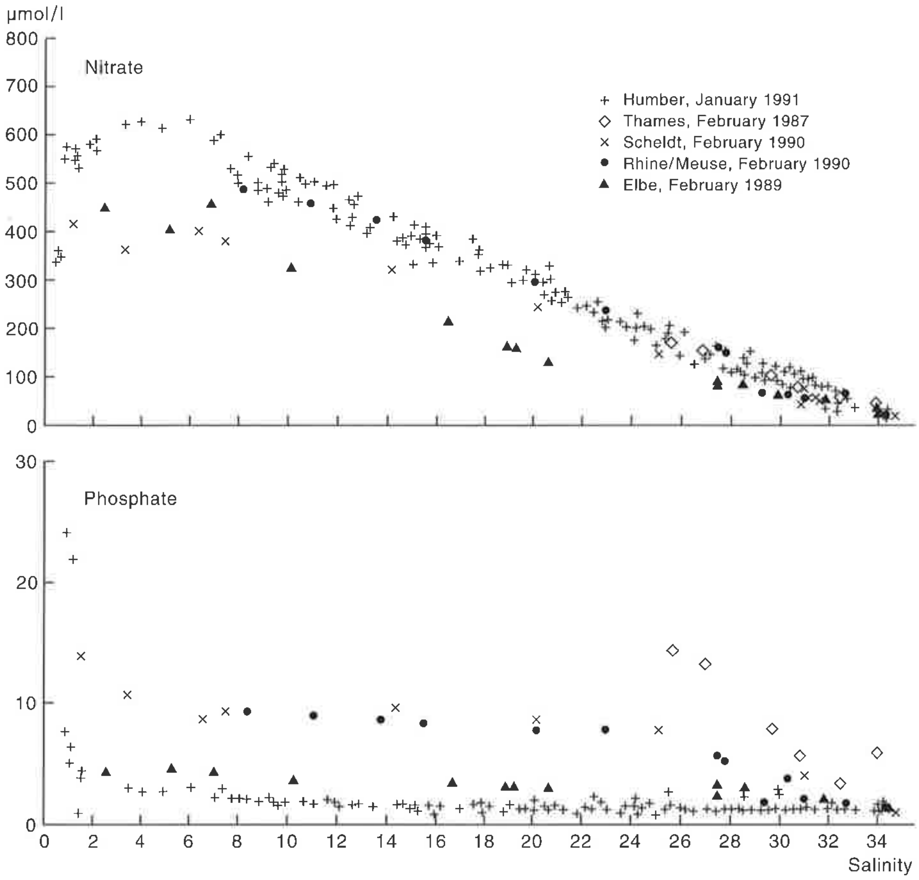


Figure 3·16. Concentrations of nitrate and phosphate versus salinity for various rivers, 1987–1991. Source of data: ICES Oceanographic Data Centre.

rivers and the Atlantic. There is significant interannual variability in river run-off and hydrography, which influences the winter concentrations and distribution of nutrients. Despite this, the overriding pattern of hydrography remains sufficiently strong to give rise to a generally predictable distribution of nutrients in the North Sea. As an example, Figure 3·17 illustrates the distribution of nitrate in surface waters in February 1989. This shows concentrations along the southeast coast of England that are higher than in the central North Sea and more strongly elevated concentrations along the south and east coasts of the North Sea from northern France to Denmark. Winter concentrations of nitrate are 8–12 µmol/l in the northern North Sea. Concentrations in the central waters of the Channel are typically < 7 µmol/l and in the surface waters of the Kattegat < 10–15 µmol/l. Low winter nutrient concentrations usually prevail over the Dogger Bank, owing to the growth of phytoplankton that consumes nutrients during winter in this shallow offshore region.

Figure 3·17 showing the distribution of nitrate in February 1989 is similar in some respects to a map of nutrient concentrations published by OSPARCOM (1993). It should be noted, however, that the OSPARCOM map is a compilation of information based on nitrate or total nitrogen or phosphate and represents an attempt to synthesize information gathered over a number of winters.

Winter distributions of phosphate show the same general pattern as for nitrate, with concentrations exceeding 1 µmol/l in most coastal areas of the southern North Sea. The highest concentrations are found along the continental coast from France to Denmark, with values of 3 µmol/l in near-shore waters.

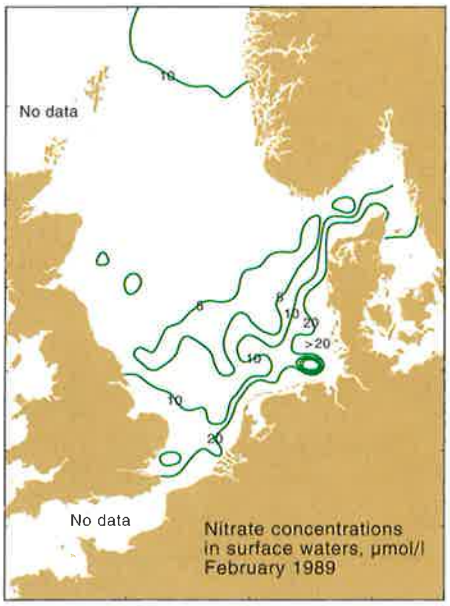


Figure 3·17. Concentrations of nitrate in surface waters of the North Sea in February 1989. Source of data: ICES Oceanographic Data Centre.

There is marked seasonality in the riverine nutrient input and in the nutrient consumption by phytoplankton in the sea. For major rivers such as the Rhine and the Elbe, the discharge of nutrients is highest during winter and spring and lowest during summer. The seasonal variation is more pronounced for nitrate than for phosphate, reflecting differences in sources and chemical behaviour. Nitrate stems mainly from diffuse agricultural and land run-off sources. More nitrate is lost from the soil with increasing precipitation, and its concentrations therefore tend to increase with river flow. Because of this pattern most of the nitrate is discharged during the winter and spring when river flows are high. For phosphate a larger proportion originates from other sources such as sewage-treatment facilities. Phosphate is strongly adsorbed to soils and desorbs at a relatively constant rate from the surface of the soil, and concentrations therefore decrease with increasing river flow.

Phytoplankton growth in spring depletes the nutrients in the upper layer of the stratified waters of the northern and central North Sea, the Skagerrak and the Kattegat, as well as the Channel. Reflecting the high riverine nitrate input in winter and spring, elevated concentrations of nitrate remain in the coastal zone along the eastern North Sea during spring and early summer following depletion of phosphate. Elevated concentrations of nitrate in the upper or intermediate layers have regularly been found in the eastern Skagerrak (Figure 3·18) and on occasion also in the Kattegat in spring during the 1980s. Based on hydrographic characteristics, the water mass containing these elevated nitrate levels has been shown to originate from the southern North Sea.

Temporal trends

In most areas of the North Sea the timing and frequency and length of time series of nutrient measurements are inappropriate or insufficient for determining temporal trends. Time series do exist, however, for a number of riverine inputs. A good example is provided by data for the Rhine which show clear trends over several decades. Nitrate has increased steadily during recent decades to the present high concentration levels. This increase is compensated by a decrease in concentrations of ammonium (mainly due to improved treatment facilities in the catchment

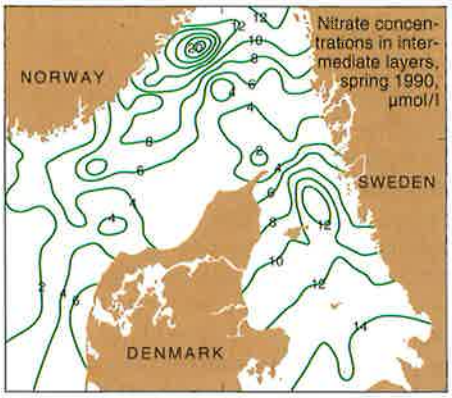


Figure 3·18. Concentrations of nitrate in the intermediate layers of the Kattegat and eastern Skagerrak in spring 1990. Source of data: ICES Oceanographic Data Centre.

area). As a consequence, total nitrogen levels remained stable.

Concentrations of inorganic phosphate and total phosphorus have, in contrast to nitrate, shown a decreasing trend during the last decade. Similar trends, with a recent increase in nitrate and a decrease in phosphate, have been noted in the Elbe.

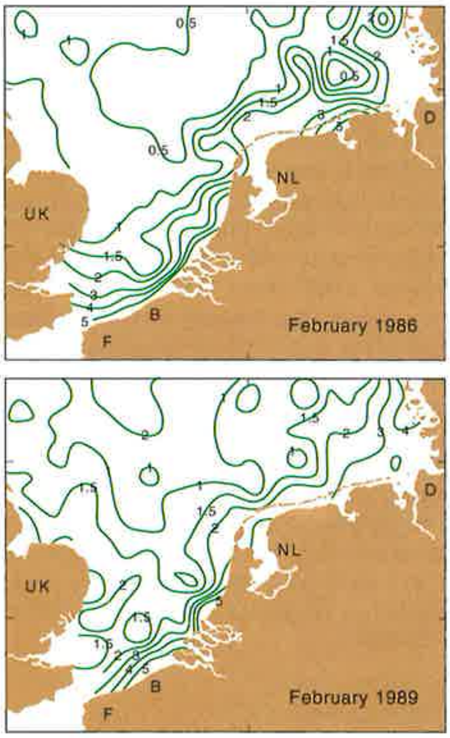


Figure 3·19. Concentrations of phosphate in surface waters of the southern North Sea, shown as the fractional increase above concentrations measured in January of 1935 and 1936, for two contrasting winter months, February of 1986 and 1989. Source of data: ICES Oceanographic Data Centre.

Older measurements of phosphate in sea water are considered reliable. The only extensive data set for nutrients in the southern North Sea prior to 1960 is for the winters of 1935 and 1936 (Weichart, 1986). Figure 3·19 shows the fractional increase in phosphate relative to January 1935 and January 1936 for two contrasting winters, February 1986 and February 1989. These maps show that phosphate concentrations, relative to the early data set, increased by a factor of 3 to 4 along the coastal strip of the southern and eastern North Sea. A doubling of the phosphate concentration corresponds approximately with the 33 surface isohaline. The area affected by a doubling or more of the winter phosphate concentration represents about 10% of the total area of the North Sea.

A similar comparison for nitrate cannot be made since there are no reliable survey data available for nitrate in sea water for the period before 1960. Concentrations of both phosphate and nitrate during winter months in the Belgian and Dutch coastal zones showed no significant change over the period 1975–1990. However, they are significantly higher than the concentration levels measured in the early 1960s: 2 to 4 times higher for phosphate and 1.5 to 3 times higher for dissolved inorganic nitrogen in the coastal zone up to 10 km offshore.

A valuable time series of observations on nutrients and phytoplankton exists for the island of Helgoland in the inner German Bight, where a high-frequency measurement programme has been carried out since 1962. Mean concentrations of nitrate and phosphate for winter (January–March) and summer (June–August) periods show clear trends during recent decades (Figure 3·20). Data for the winter period normalized for salinity show the same basic trends (Hickel *et al.*, 1989; Körner and Weichart, 1991). The nitrate concentrations at Helgoland have shown a marked increase since the late 1970s for both winter and summer periods. Mean winter concentrations ranged from 25 to 40 µmol/l during the 1980s, while in recent years mean summer concentrations have also exceeded the natural background concentration for Atlantic water. Phosphate shows a different trend, with an increase up to the late 1970s and a decrease during the 1980s. The recent decrease in winter phosphate from 1988 to 1990 appears to be mainly a reflection of an increase in salinity, since the salinity-normalized data show an increase rather than a decrease.

A trend analysis of winter nutrient data from waters off the east coast of the United Kingdom (Dickson *et al.*, 1988) did not show any significant change in concentrations of nitrate

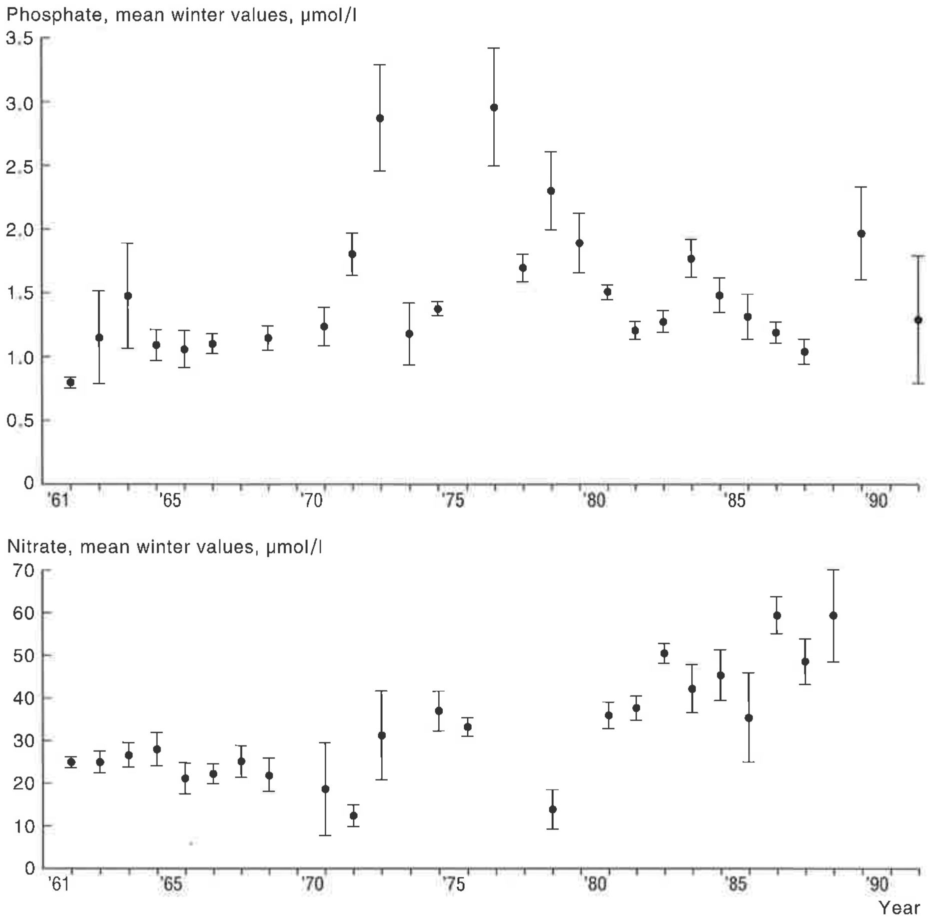


Figure 3·20. Dissolved nutrient concentrations near Helgoland in the German Bight, 1961–1991, calculated for a salinity of 30 from regressions of NO_3 and PO_4 against salinity for all winter values (December–February) where a significant negative correlation with salinity was found.

over the last three decades. Similarly, a trend analysis of phosphate concentrations for the Southern Bight showed no statistically significant change over the same period. Salinity normalization was not applied in the latter analysis, however, and there are strong gradients in salinity and nutrient concentrations in this region which would tend to mask trends in averaged data.

Inputs of silicate are mainly from natural sources, and the concentrations in rivers have remained more or less unchanged.

Nutrient ratios

Nutrient composition can influence algal species composition owing to differences among classes and species of algae in their physiological properties and specific requirements for nutrients. In addition to nitrogen and phosphorus, silicate is a nutrient required by an important class of algae, the diatoms, which use silica in their body structure. Riverine discharges to the coastal zone of the southern North Sea carry high concentrations of silicate. In contrast to nitrogen and phosphorus, however, silicate has not increased in recent decades. Silicate is therefore now typically the first nutrient to become depleted in coastal waters during spring, arresting further growth of diatoms in the spring bloom. The remaining surplus nitrogen and phosphorus allow growth of algal types that do not require silicate, such as a variety of flagellates including the colony- and foam-forming *Phaeocystis* sp. which forms massive blooms in spring and summer in some coastal waters of the North Sea (Billen *et al.*,1991).

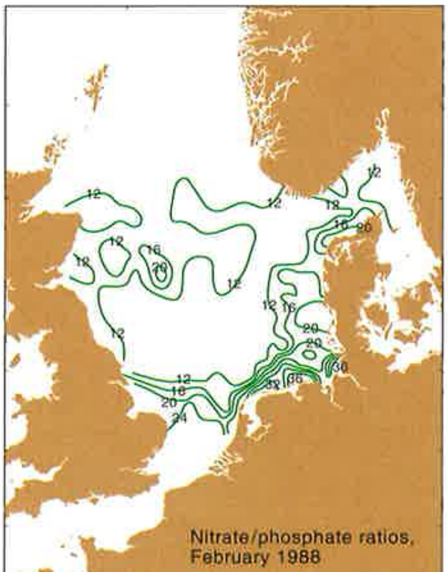


Figure 3·21. Nitrate/phosphate ratios in sea water in February 1988. Source of data: ICES Oceanographic Data Centre.

The present situation with high inputs of nitrate from river discharges and relatively lower inputs of phosphate (due to abatement measures on phosphorus inputs) is reflected in the N/P ratio in the sea. Figure 3·21 shows a band of water with elevated N/P ratios in winter stretching from the southeast coast of England to north of Denmark. The effect of the strong reduction in river-discharged phosphorus is even more noticeable in brackish areas of the estuaries where nitrogen/phosphorus (N/P) ratios up to 200 were reported. Marine phytoplankton consume nitrogen and phosphorus in a ratio of about 16:1, and under normal circumstances in the marine environment nitrogen is the limiting nutrient. However, the surplus of nitrogen has led to a condition where phosphorus limitation of phytoplankton photosynthesis now occurs in spring/early summer in some coastal regions where a substantial amount of nitrogen remains in the water as nitrate after phosphorus has become depleted. This condition has been observed regularly in recent years in coastal waters of the southern and eastern North Sea. The excess nitrogen in these areas is advected to other regions, where it both increases the total nitrogen available and changes the N/P ratio. A change in N/P ratio affects phytoplankton species composition and may stimulate toxin production in some species.

Coastal waters from the southern North Sea are transported by the Jutland current into the Skagerrak and partly into the Kattegat. Waters with high nitrate contents and high N/P ratios have been found consistently as an intermediate water layer in the eastern Skagerrak and the Kattegat in spring or early summer since the late 1980s (Figures 3·18 and 3·21).

Oxygen

Most of the North Sea is permanently or seasonally mixed; hence, most areas are generally well ventilated, and oxygen concentrations are close to the saturation level in surface and deep water for most of the time. Low oxygen concentrations have been reported to cause problems, however, in some local estuarine and coastal areas as well as in some restricted offshore areas (Box 3·10).

In the central North Sea (particularly Subregion 7a), the deep water may be characterized by partial oxygen depletion, with concentrations as low as 70% of saturation levels in early autumn (October). However, a German study has shown that for the last 80 years there has been no trend in oxygen concentrations in the bottom water in this area. Farther south, on the Oyster Ground, oxygen concentrations may fall to around 50% of saturation levels during longer periods of stable stratification. However, in the neighbouring Dutch coastal zone, oxygen never falls below 70% saturation, with the exception of the Western Scheldt Estuary, where the bottom water is anoxic in summer owing to degradation of organic matter derived from land-based sources.

Oxygen depletion has occurred during several years recently in areas of the German Bight under conditions of stratification and calm weather in summer. A more serious situation occurs in the open waters of the southern and eastern Kattegat, where in August–October, and sometimes also in the spring, oxygen concentrations can reach very low values; at certain times, extremely low values (below 5–10% saturation) may occur and create virtually anoxic areas. Oxygen concentrations in Kattegat deep water have shown a decreasing trend over the last two decades, with periods of oxygen deficiency becoming more frequent and of longer duration in the 1980s. However, after mixing and exchange of water masses, conditions return to normal in late autumn.

In the eastern Skagerrak, some coastal areas in the Swedish archipelago, and Norwegian fjords with restricted water exchange, low oxygen concentrations are experienced during the summer. It remains unclear to what extent this situation is caused by increased production and transport of

Box 3·10. *The origin of oxygen depletion*

When organisms die, they are decomposed and degraded by micro-organisms. The same processes apply to organic matter of anthropogenic origin. This degradation process requires large quantities of dissolved oxygen in the water. Most of the organic matter sediments to the seafloor, and therefore this oxygen consumption will take place mainly in bottom waters. In areas with stratification separating surface water from bottom water (at least during some periods of the year) the replenishment of oxygen from the atmosphere is slow or even insignificant. The degradation of organic matter under conditions of stratification constitutes the main reason why oxygen deficiencies repeatedly occur in certain sea areas during specific periods of the year. The slow replacement of deep water may also contribute to oxygen deficiencies.

Oxygen dissolved in sea water is an essential constituent of marine life. However, the decomposition of organic matter in restricted water bodies can lead to oxygen deficits. Extreme oxygen deficiency may lead to anoxia, when the action of bacteria causes the reduction of sulphate to sulphide, which is toxic to marine organisms.

organic material or by changes in hydrographic conditions and water exchange. Some Norwegian and Swedish fjords in the Skagerrak area have permanent anoxic conditions in their deep waters. In most tidal estuaries, depressed levels of dissolved oxygen are a natural phenomenon due to natural organic loading. These situations occur in periods of low river flow in summer, when oxygen levels can go down to 50–60% saturation. However, in many large estuaries around the North Sea (e.g., the Humber and the Scheldt estuaries), the inputs of organic matter from sewage, agriculture, diffuse sources, and industrial effluents aggravate the natural situation and extend the area affected, the duration, and the level of dissolved oxygen depression. In several areas seriously affected in the past, improvements have been observed after treatment of effluents (e.g., the Thames, Humber, Seine, and Elbe estuaries).

Nutrients and sediments

Sediments act as a source of, and a sink for, nutrients in the water column and play a key role in the processes governing fluxes from estuaries to the sea. While the role sediments play is now well recognized, there have until recently been few measurements of nutrients in sediments, other than total nitrogen and organic carbon. Data on pore water in sediments are only included in one subregional assessment report for estuarine and coastal waters in the Channel (Subregion 9). Here nutrient concentrations in pore water are generally much higher than in the water column and are higher in the summer. These patterns were confirmed for the North Sea in nine pore water profiles sampled by Law and Owens (1990).

Their study focused on denitrification (the production of the gas N_2 by the microbial breakdown of organic detritus with nitrate as a substrate in the absence of oxygen) and the production of the greenhouse gas nitrous oxide in the North Sea. Denitrification rates in the North Sea were low compared with those in most estuaries, but varied by three orders of magnitude; the highest value of 150 µmol N/m^2/day was recorded in samples from the Norwegian Trench. Nitrous oxide production by sediments was low, < 1 µmol/m^2/day. The authors estimated that approximately 10% of anthropogenic inputs of nitrogen to the North Sea are lost to the atmosphere through denitrification. For the Danish Belt Sea and the western and eastern Kattegat, annual denitrification rates between 140 and 350 µmol N/m^2/day have been reported by Blackburn and Henriksen (1983). Recent findings (Lomstein and Blackburn, 1992) also suggest that denitrification may be an important process in the water column and could be a significant component of the nitrogen budget.

3.5 Influence of anthropogenic inputs on levels and trends

It will be clear from the earlier sections of this chapter that there is insufficient information on the spatial distribution of synthetic organic compounds in the North Sea; their concentrations, however, are elevated in some areas and a number of them may be widely distributed.

With respect to metals and nutrients, elevated levels are largely confined to coastal areas of the North Sea. These elevated levels are not solely due to anthropogenic activities but also arise via the natural introduction of these substances through run-off. The cause of these elevated concentrations clearly lies in past and continuing introductions of substances as a consequence of human intervention. Because of the introduction of contaminants in the past and their present widespread elevated concentrations, it is not possible in most instances to identify a specific source. In addition, even where point sources of input are clearly identifiable, unless they are very large and/or enter an area of restricted water movement, the natural dispersive forces of the marine environment often make it difficult to detect any possible effect in terms of elevated environmental concentrations close to the site of input.

For the more persistent substances, such as most metals, halogenated organic compounds, and polycyclic hydrocarbons, which adsorb onto particulate material, sediments can give a better indication of the impact of local sources than water or mobile marine organisms. Two layers may be recognized in the sediments:

- the upper part of the sediment (10 to 30 cm), which is normally bioturbated and mixed (the dynamic layer);
- the underlying sediment, which is less well mixed and less closely in contact with the living biomass (the permanent layer).

Contaminants stored in the dynamic layer may influence sediment-dwelling animals and the quality of bottom water by diffusive and advective processes. In the permanent layer the contaminants are stored with minimal environmental impact. This suggests that the environmental implications of contaminated sediments depend to a great extent on the natural rate of sedimentation. If the rates are high, the time taken to transfer accumulated contaminants from the dynamic to the permanent layer is short. For a given rate of input to the environment there will also be a dilution effect if the flux of natural particulate material to the seabed is high.

Survey data of contaminants in sediments clearly show that most of the estuaries of the east coast of England have been affected by inputs of metals, as have several Norwegian fjords. In neither case are the effects readily detectable offshore, i.e., beyond the immediate coastal zone. Another area clearly affected by both metals and organic contaminants is the German Bight. Higher concentrations of certain contaminants are also detectable in the deeper area sediments of the Skagerrak and Norwegian Trench; the contaminants are derived from a multitude of distant sources (Lohse, 1988) and occur here because these areas are deposition areas.

Direct releases of metals and organic contaminants in the North Sea are decreasing, so it is inevitable that the bottom surficial sediments of net sedimentation areas will gradually become cleaner.

In quiet areas the contaminated sediments will become buried under cleaner sediments, such as in a Scottish fjord, where a survey of a former dumpsite showed that over a period of ten years a layer of about 4 cm of relatively clean sediment had been deposited on the contaminated sediment.

In areas such as the Wadden Sea and also some parts of the Kattegat where there is much bioturbation, the contaminated sediments will mix with the cleaner sediments. Depending on the sedimentation rate, the dynamics, and the contamination level of the imported sediments it may take centuries before the sediments in such areas can be regarded as clean.

Concentration profiles in undisturbed sediments taken from the Wadden Sea near Sylt indicated that concentrations of copper, zinc, cadmium, and lead began to increase roughly 100 years ago, at a core depth of 80 cm. Polychlorinated biphenyls were absent from the sediments until 1933 (ca. 48 cm depth). In modern surficial sediments, concentrations of zinc, mercury, and lead are twice the estimated background concentrations, whereas copper concentrations are not elevated, and those observed for cadmium are from 3 to 12 times higher (depending on location) than the concentrations found in a sample dated between 0 and AD 500. Sediments dated as 200 years old from the southern Norwegian coast on the Skagerrak are regarded as containing metals at background levels. Here, the sedimentation rate has been low (1 mm/year) and measured levels in samples from 383 m depth were: mercury, 0.02 mg/kg; cadmium, 0.08 mg/kg; copper, 21 mg/kg; lead, 21 mg/kg; and zinc, 90 mg/kg. Farther east along the coast, sediment samples of 30 to 40 years old were sampled from 350 m depth in the Norwegian Trench where the sedimentation rate is 5 mm/year and the measured metal levels were: mercury, 0.07 mg/kg; cadmium, 0.08 mg/kg; copper, 25 mg/kg; lead, 43 mg/kg; and zinc, 150 mg/kg.

The overall impact of input sources in terms of concentrations of contaminants in the water column is not readily detectable in most areas. Nutrients are a notable exception in this context, and Section 3.4 describes a number of areas around the North Sea where higher concentrations are found, e.g., close to a number of estuaries on the English east coast, in the Baie de Seine, and particularly along the continental coast from Belgium to Denmark, at least during the winter period of minimum phytoplankton growth.

Decreases in inputs of nutrients will, in principle, lead to reductions in nutrient concentrations in the water column during winter in coastal waters. However, these concentrations are also influenced by a number of other factors, such as uptake in organisms, release from organisms, changes in sedimentation rate or pattern, temporal or periodic changes in water transport patterns, and the recycling of nutrients. Therefore, even if the concentrations do decrease it will be as difficult in the future as it has been in the past to demonstrate such trends throughout the annual cycle.

In consequence, a response in the environment to the decreased discharges of nutrients should be sought not only in the form of decreasing nutrient concentrations in the water but also as decreased primary production in areas where plankton blooms are known to cause problems and in a decreased frequency of occurrence and extent of anoxic or partly anoxic seabeds and bottom waters.

There have been few serious attempts to assess changes in contaminant concentrations over time, and there are few good data series that allow reliable conclusions to be drawn. Notable exceptions to this are the data sets on nutrient concentrations off the Dutch coast and off Helgoland (see 'Temporal trends', p.57) and the studies of contaminants in biota referred to in 'Spatial distribution ...', p.44. These data sets show that artificially high levels of inputs of persistent substances that are steadily increased or maintained are eventually detectable in the environment if good time-series data are collected. They also show that if reduction measures are introduced, they do lead to a reduction in concentrations in the environment, albeit in some cases rather slowly.

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CHAPTER

4

Marine biology

4.1.

Introduction

The 1987 *QSR* described only the ecological effects attributable to human activities and their impact on the seabed and coastal flora, as well as on the plankton, fish stocks, seabirds, and mammals. The report did not provide a description of the biological components of the marine ecosystem.

The 1990 *QSR* focused on the effects of pollution on plankton populations in the North Sea and, in particular, on algal blooms. A seal disease epidemic that broke out in April 1988, with a significant impact on many harbour and grey seal populations, was also discussed in the report. In the wake of the epidemic, an extensive array of research projects was initiated that has led to greater knowledge about the status of seal colonies all around the North Sea.

This chapter describes the complexity of biological systems in the North Sea. General information on plankton, invertebrates, and vertebrates and their status in the North Sea is given first, followed by an assessment of recent changes. Interrelationships between communities are also discussed in order to present an overall description of the North Sea as an ecosystem.

4.2.

General description of the marine biota

Plankton

Bacterioplankton

The importance of micro-organisms (principally bacteria, but also yeasts, fungi, and virus-like particles) in the marine food web has only been recognized and investigated during the last twenty years (Billen *et al.*, 1990). Some 60% of primary production (conversion of light energy into biologically usable energy via photosynthesis) may enter microbial food webs in which the main consumers of bacteria are microflagellates. Planktonic bacterial production in the open sea is related to primary production, and the abundance of bacteria increases, following phytoplankton blooms. Sea water contains around 10^9 bacteria per litre, which live mainly on organic matter produced by algal secretion, exudation, and lysis of cells. Bacteria remineralize organic matter to inorganic components.

Phytoplankton

Phytoplankton are microscopic, free-floating, usually single-celled, algae. These organisms are responsible for most of the primary production that occurs in the North Sea. Phytoplankton in the North Sea range in length from less than 0.001 mm up to 2 mm.

The size structure of the phytoplankton community is important in determining the efficiency of energy transfer through the food chain to the species of commercial interest. A population dominated by small cells (picocyanobacteria and flagellates) is highly productive, but the flux of energy to the next higher level is low. A population composed of larger cells (diatoms, dinoflagellates) is much more efficient in the transfer. Therefore, shifts in the population size structure will affect energy fluxes in the ecosystem in terms of their relative efficiency in transfer to species at higher trophic levels, including commercial species. Such shifts in populations can occur as a result of changes in nutrient inputs (total and relative quantities).

Most phytoplankton have very rapid maximum doubling times (of the order of < 1–3 days). When light and nutrient conditions are favourable, 'blooms' of these organisms can develop. Such blooms occur, for example, each spring in the North Sea.

There is a complex interaction between phytoplankton abundance and productivity and nutrient and light availability and the degree of mixing in the water column. The interaction plays a role in the geographic heterogeneity of phytoplankton distribution (Figure 4·1A), and presumably controls phytoplankton species succession in the North Sea. However, this interaction is not yet fully understood. Spatial and temporal heterogeneity in the abundance of larger (> 280 µm) phytoplankton in the North Sea can, for example, be demonstrated using data collected with the Continuous Plankton Recorder (CPR) (Box 4·1; Figures 4·1C and 4·1E).

There have been a number of examples of unusual or exceptional blooms of phytoplankton in the North Sea; given our present state of knowledge their occurrence is unpredictable. Here the term 'unusual algal blooms' refers to a large biomass production or to the occurrence of a species that has the potential for causing noxious effects. These blooms may or may not be blooms in the sense described above, but they are

Box 4·1. *The Continuous Plankton Recorder*

Continuous Plankton Recorders (CPR), which filter and trap plankton between two constantly winding lengths of 280 µm mesh silk, have been towed behind merchant ships at monthly intervals on regular routes across the North Sea since 1931. On average about 750 samples per year are analysed for the whole North Sea. They provide the only extensive and systematic information on community structure, spatial distribution, and seasonal and annual changes in plankton abundance. As such the surveys are of immense value in making it possible to distinguish between changes caused by local factors such as river outflow, and those caused by large-scale events such as weather patterns. For example, populations of most species of zooplankton (and large phytoplankton) in the North Sea declined between 1950 and 1980 and have since increased. The same trend can be observed in offshore parts of the North Sea and also in the open Atlantic from Iceland to the Bay of Biscay, therefore the cause of the decline was not local. It must be noted, however, that phytoplankton data from the survey need to be interpreted with care as most species pass through the coarse mesh of the silk. Since 1991 the survey has been operated by the Sir Alister Hardy Foundation for Ocean Science (named after the founder of the surveys).

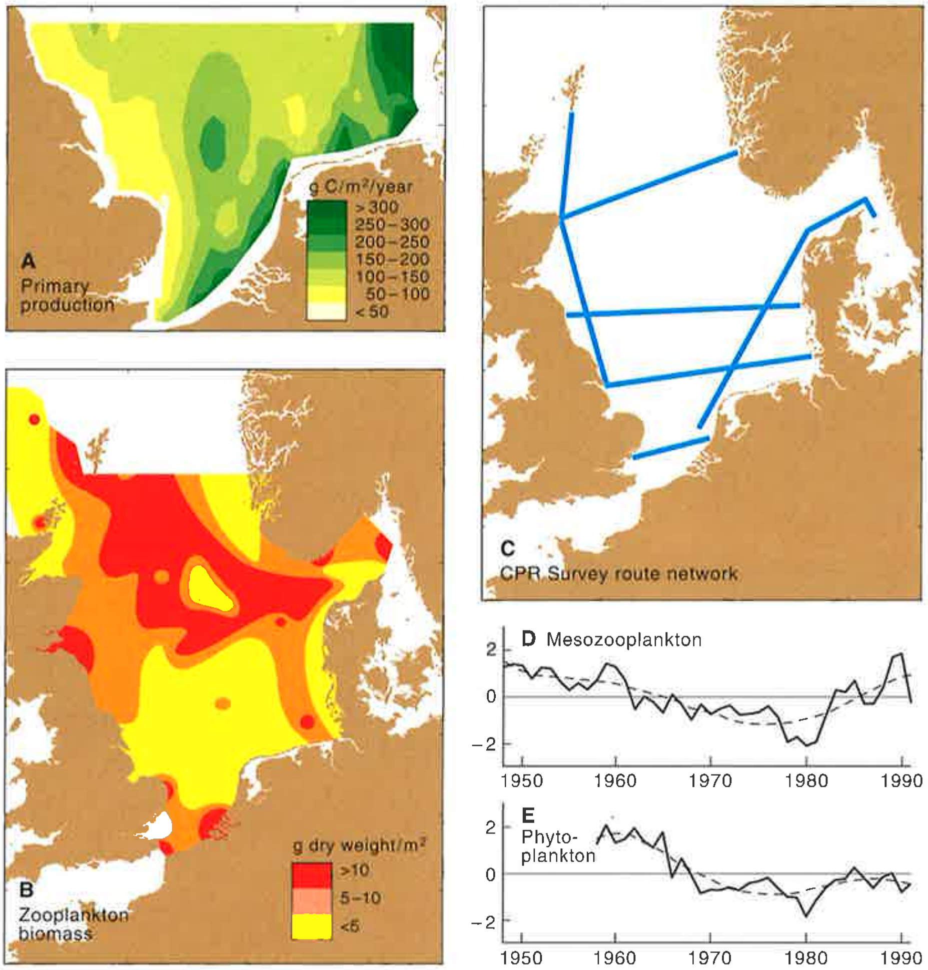

Figure 4·1. Plankton of the North Sea.
A: Annual primary production in the southern North Sea. Source: Joint and Pomeroy (1992).
B: Horizontal distribution pattern of zooplankton biomass in the North Sea, 2 May – 13 June 1986. Source: Krause and Martens (1990). Distribution of zooplankton biomass varies between seasons and between years, and the pattern shown represents only the period of sampling.
C: Present route network of the CPR Survey in the North Sea. Source: CPR Survey Team (1991).
D: Abundance of mesozooplankton in the North Sea, sampled by the CPR Survey, 1948–1991. Source: CPR Survey Team (1991). Data are standardized to zero mean and unit variance. The decline from 1950 to 1976 and subsequent increase occurred throughout most of the North Atlantic, as a result of large-scale (e.g., climatic) rather than local (e.g., eutrophication) effects.
E: Abundance of phytoplankton (>280 µm) in the North Sea, sampled by the CPR Survey, 1948–1991. Source: CPR Survey Team (1991). Data are standardized to zero mean and unit variance.

characterized by the presence of a phytoplankton species that arouses public concern. This concern can be caused by water discoloration (e.g., *Noctiluca* spp.), foam production (e.g., *Phaeocystis* spp.), fish or invertebrate mortality (e.g., *Chrysochromulina* spp., *Gyrodinium* spp.), or toxicity to humans (e.g., *Alexandrium* spp., *Dinophysis* spp.). Nutrient inputs from terrestrial sources may increase nutrient availability (and thus, increase the duration and intensity of blooms), but they do not necessarily initiate unusual blooms. Algal blooms, including unusual ones, are natural events that may or may not be associated with anthropogenic causes. For example, *Phaeocystis* spp. blooms have occurred in the North Sea for many years and can hardly be regarded as unusual. However, an increase in the dominance of *Phaeocystis* (cell numbers as well as duration of the bloom) between the mid-1970s and the late 1980s has been reported for the Marsdiep region (the westernmost Wadden Sea inlet). Levels of chlorophyll and primary production also increased over this period, but have decreased since then. These changes can be attributed to trends in eutrophication.

Zooplankton

Zooplankton are small animals living in the water column and transported mainly by water movement. They range in size from unicellular ciliates, flagellates, Radiolaria, and Foraminifera (microzooplankton < 0.2 mm) to krill, jellyfish, and fish larvae (macrozooplankton > 2 mm). The mesozooplankton (0.2–2 mm) are principally herbivorous copepods, which constitute 70–80% of zooplankton biomass in the North Sea and form the major link in the food chain between phytoplankton and fish larvae (Box 4·2).

Grazing by zooplankton is one of the major factors controlling phytoplankton populations. However, certain species of phytoplankton can repel grazers. For example, *Alexandrium tamarense* is regurgitated by copepods and it repels tintinnids (*Favella* spp.). Mesozooplankton graze on 40 to 100% of the phytoplankton production, but there are certain species of phytoplankton such as *Phaeocystis* spp. that are avoided (Davies *et al.*, 1992). The proportion of matter arising from primary production that settles to the seabed may thus be increased and the proportion remaining in the pelagic food web reduced.

Knowledge of the distribution of zooplankton throughout the North Sea is limited to a few extensive surveys (Figure 4·1B) and the Continuous Plankton Recorder surveys, which also show temporal trends in abundance (Figure 4·1D). Zooplankton abundance varies between areas owing to differences in production, predation, and transport. Most of the northern and central North Sea is dominated by oceanic species, particularly the copepod *Calanus finmarchicus*, whereas the southern North Sea and coastal areas are populated by neritic (open water) species (e.g., *Temora* spp., including high concentrations that have been reported in the Marsdiep area).

The eggs and larvae of most fish species are planktonic for a few months, and this period is critical in determining their year-class abundance. The growth and survival of fish during their planktonic stage depends on adequate feeding conditions, low levels of predation, and transport of larvae to suitable nursery areas.

Box 4·2. *Zooplankton*

Some species (Copepods, Euphausiids, and *Sagitta* spp.) remain as zooplankton throughout their life (holoplankton), whereas others have a zooplanktonic stage during their early life history (meroplankton). The latter group includes the eggs and larvae of most species of bony fish and also of a wide variety of the animals that live on the seabed and in the sediments. For example, sea urchins, starfish, molluscs, and polychaete worms all have a planktonic stage as do shrimps, crabs, hermit crabs, and lobsters.

In the North Sea these early life history stages are most abundant in the plankton during spring and summer, coinciding with the period of highest primary production. A general feature of this distributive planktonic stage is that large numbers of small eggs and larvae are produced, which grow rapidly but suffer very high mortality rates during their period in the plankton.

Box 4·3. *Categories of benthos and commercially important North Sea species*

Phytobenthos

Microphytobenthos: diatoms, flagellates, and other unicellular algae.

Macrophytobenthos: red, brown, and green algae, and sea grasses. The kelp *Laminaria hyperborea* is commercially used for alginate production.

Zoobenthos

Zoobenthos are divided into:

Epifauna: zoobenthos that live primarily on or above the sea bottom. Commercially important are lobsters (*Homarus gammarus*), spiny lobsters (*Palinurus vulgaris*), Norway lobsters (*Nephrops norvegicus*), brown crabs (*Cancer pagurus*), deepwater prawns (*Pandalus borealis*), shrimp (*Crangon crangon*), whelks (*Buccinum undatum* and *Neptunea antiqua*), periwinkles (*Littorina littorea*), scallops (*Pecten maximus*), queens (*Aequipecten opercularis*), oysters (*Ostrea edulis*), and the introduced Portuguese oyster (*Crassostrea angulata*), Pacific oyster (*Crassostrea gigas*), and blue mussels (*Mytilus edulis*). Oysters and blue mussels are cultivated on special beds or are grown on poles and ropes in sheltered areas.

Infauna: zoobenthos living within the sediment (polychaete worms, crustaceans, bivalves, gastropods, and members of many other animal groups). Commercially important are cockles (*Cerastoderma edule*) used as human food and lugworms (*Arenicola marina*) for bait.

Infauna are split into categories according to size:

Microfauna: animals smaller than 50 µm, including ciliates, flagellates, protozoans, bacteria, and fungi.

Meiofauna: Foraminifera, nematodes, crustaceans such as harpacticoid copepods, and members of many other animal groups that are so small they pass a 1 mm mesh. Many live in the interstices between sand grains.

Macrofauna: animals larger than 1 mm.

Benthos, including shellfish

General definition

The biota living near, on, or in the seabed are collectively called the benthos (Box 4·3). Bottom-dwelling and commercially important molluscs and crustaceans are called shellfish. A distinction is made between plants (phytobenthos) and animals (zoobenthos), which either live within the sediment (infauna) or move about on its surface (epifauna). Typical benthic fauna communities in the North Sea are shown in Figure 4·2. The infauna are split into categories according to size: macrobenthos/macrofauna (animals larger than 1 mm), meiobenthos/meiofauna (animals between 50 µm and 1 mm), and microbenthos/microfauna (animals smaller than 50 µm).

Both phytobenthos and zoobenthos are used in many monitoring programmes because they live permanently in or on a substrate and integrate the effects of the various environmental conditions.

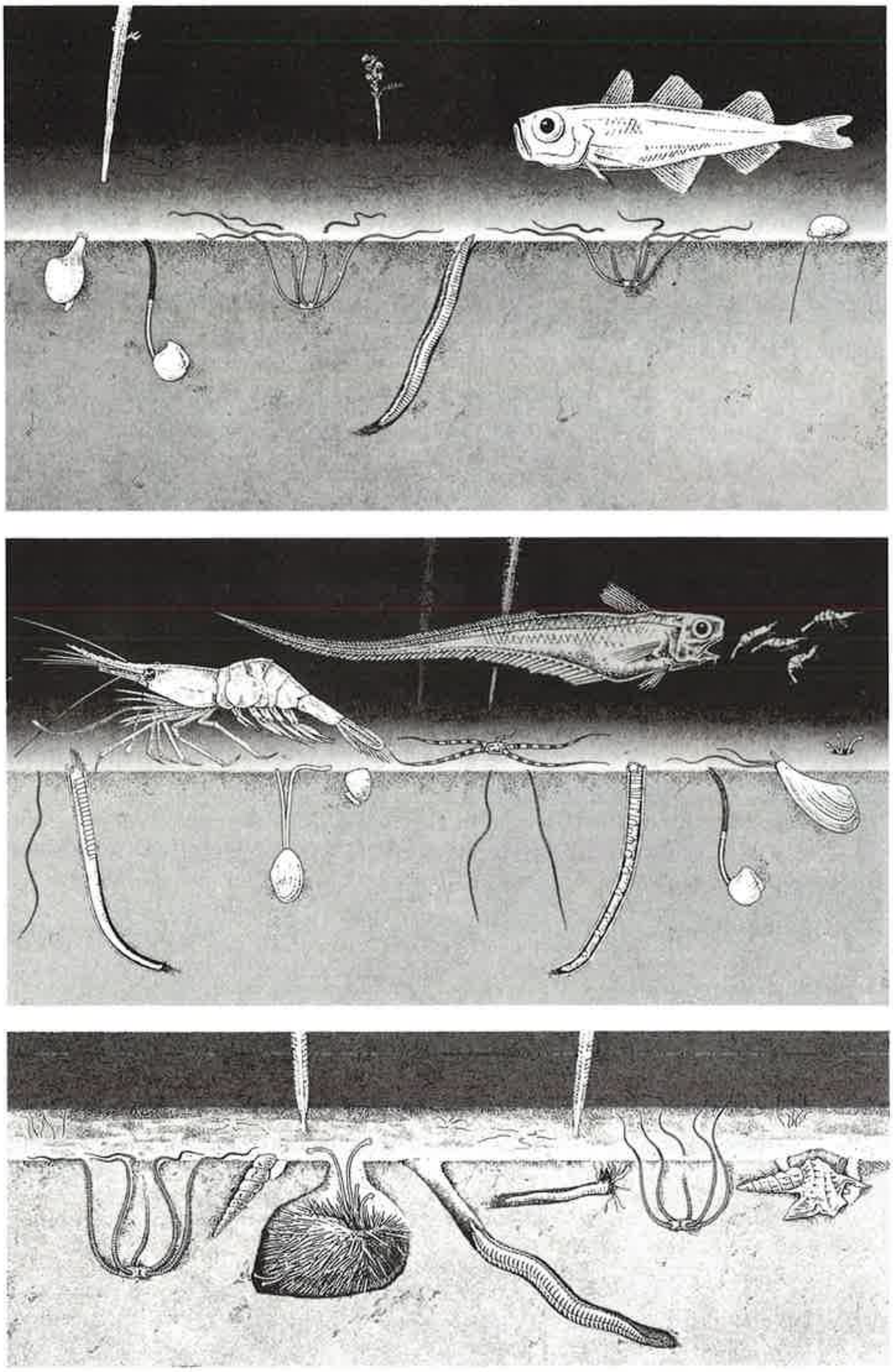

Figure 4·2. Conceptual views of the animal communities living on or in the bottom sediments of the North Sea.
Source: after Thorson (1979).

A: Deep Skagerrak, depth 400–700 m.
A silvery pout (*Gadiculus thori*) swims above the mud bottom, from which sea pens (*Kophobelemnon stelliferum*) rise. To the right, a tiny scallop (*Pecten vitreus*) is anchored by a byssus-thread to the mud. Infauna (from left to right): the clams *Cuspidaria obesa* and *Thyasira equalis*, the brittle star *Amphilepis norvegica*, and the polychaete *Orbinia norvegica*.

B: Skagerrak, depth 150–400 m.
A grenadier (*Coryphaenoides rupestris*) hunts for deepwater prawn (*Pandalus borealis*, enlarged specimen in left foreground). In the background, sea pens (*Funiculina quadrangularis*) rise from the sediment. On the surface of the mud there is a brittle star (*Ophiura sarsi*). Buried in the mud (from left to right): the clams *Abra nitida*, *Nucula tenuis*, *Thyasira equalis*, and *Nuculana pernula*; the polychaetes *Myriochele* spp. (very thin, thread-like tubes), *Melinna cristata*, and *Maldane sarsi*.

C: Skagerrak–Kattegat region, sandy mud bottom, depth 20–100 m.
A classic '*Amphiura* community'. Epifauna are represented by two sea pens (*Virgularia mirabilis*) anchored in the sediment. In the centre is the burrow of the polychaete *Nephtys ciliata*, a predator. Other animals feeding close to the sediment surface (from left to right): the brittle star *Amphiura chiajei*, the snail *Turritella communis*, the heart urchin *Brissopsis lyrifera*, the polychaete *Terebellides stroemi*, the brittle star *Amphiura filiformis*, and the snail *Aporrhais pespelecani*.

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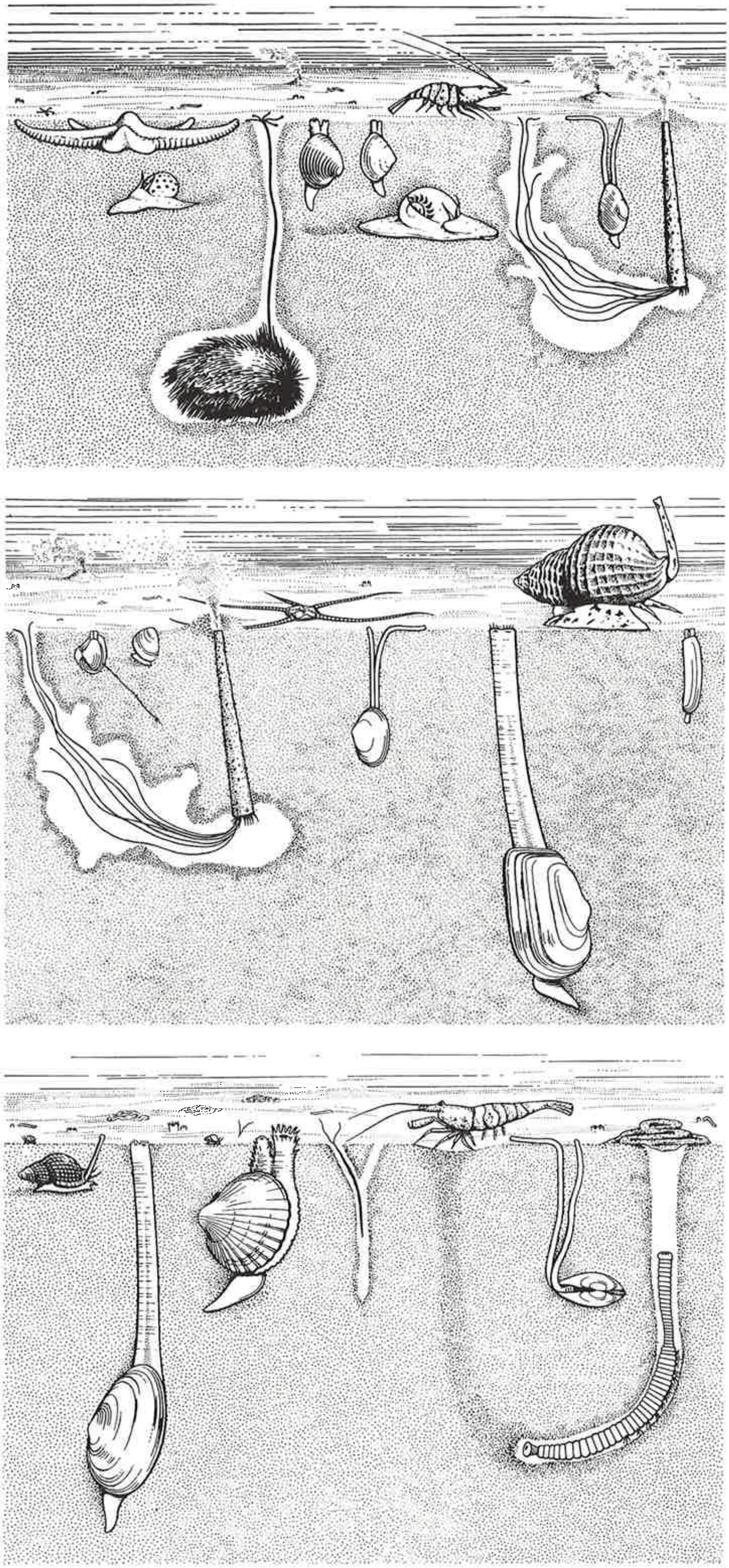

Figure 4·2 continued.

D: Skagerrak–Kattegat region, sandy bottom, depth 10–40 m.
A classic '*Venus* community'. Epifauna are represented by the shrimp *Leander adspersus*, searching for prey at the sediment surface. The sea star *Astropecten irregularis* preys on clams, as do the snails *Natica* spp. that move within the sand and, on contact, drill a hole through the clam shell. Clams are represented by (from left to right): *Venus striatula*, *Spisula subtruncata*, and (with two long siphons extending to the sediment surface) *Tellina fabula*. Buried deep in the sediment are the heart urchin *Echinocardium cordatum* and the polychaete *Pectinaria koreni*.

E: Near-shore sandy mud.
A classic '*Abra* community'. Epifauna are represented by the brittle star *Ophiura texturata* and the whelk *Buccinum undatum*. Four species of clams are abundant (from left to right): *Corbula gibba* (fastened by a byssus-thread to deeper sediment layers), *Nucula tenuis*, *Abra alba* (with its long ingestion siphon sampling particles from the sediment surface), and *Cultellus pellucidus*. Buried deep in the sediment is the clam *Mya truncata*. To the left, the polychaete *Pectinaria koreni* blows sediment particles through its conical tube into the water above, causing bioturbation.

F: Sandy bottom in shallow water or on tidal flats.
A classic '*Macoma* community'. Epifauna at the sediment surface are represented by minute snails, *Hydrobia ulvae*, and by the shrimp *Crangon vulgaris*. Below the sediment surface there is a predatory snail (*Nassarius reticulatus*). Buried in the sediment are (from left to right): the sand gaper clam *Mya arenaria*, the cockle *Cerastoderma edule*, the polychaete *Pygospio elegans*, the clam *Macoma balthica*, and the lugworm *Arenicola marina*, which feeds at depth from a sand column sunk into the sediment.

Sediment-dwelling bacteria and benthic animals play the major role in the decomposition of organic particles that originate from primary production in surface waters and settle on the sea bottom, or that are advected downslope from shallow to deep regions. Meiofauna mainly feed on sediment-dwelling bacteria and, at shallow depths, on microphytobenthos (benthic algae). Most macrofauna feed on organic particles and on bacteria in the sediment and at the sediment surface (deposit-feeding), or feed on suspended matter in the near-bottom water (filter-feeding). Other meiofauna and macrofauna species are predators. By burrowing in the sediment, ventilating burrows, and similar mechanical activities collectively called bioturbation, infauna animals facilitate the transport of oxygen down into the sediment. Areas of hard substrate near the coast are occupied by sessile and sedentary species that support mobile grazers, predators, and scavengers. Infauna and epifauna are the food of demersal fish, and meiofauna are an important food for certain species of flatfish. Some molluscan and crustacean epifauna are of commercial importance. Shellfish exploited for human consumption consist of two very dissimilar types of animals: a) crustaceans such as shrimps, crabs, and lobsters, and b) various groups of molluscs such as whelks (*Buccinum undatum*), bivalves (including cockles (*Cerastoderma edule*), mussels (*Mytilus* spp.), oysters (*Ostrea* spp.), and scallops (*Pecten* spp.)), and cephalopods such as squid (*Loligo* spp.) and cuttlefish (*Sepia officinalis*).

Benthic bacteria

The organic content of sediments is a reasonable predictor of benthic bacterial production and biomass. Benthic bacteria show great metabolic diversity, utilizing oxygen, nitrate, or sulphate as their reduction substrate. Their respiratory activity creates a chemical gradient within the sediment, with oxygen-utilizing forms found closest to the sediment/water interface and sulphate-utilizing forms at greater depths. Bacterial production is known to increase following the annual sedimentation of the spring phytoplankton bloom. There is also evidence that grazing of micro-organisms by benthic meiofauna enhances bacterial production and stimulates detrital decomposition, although the importance of this grazing to the micro-organisms is not well understood. Higher numbers of oil-degrading bacteria found in sediments in the central North Sea may be due to high oil concentrations.

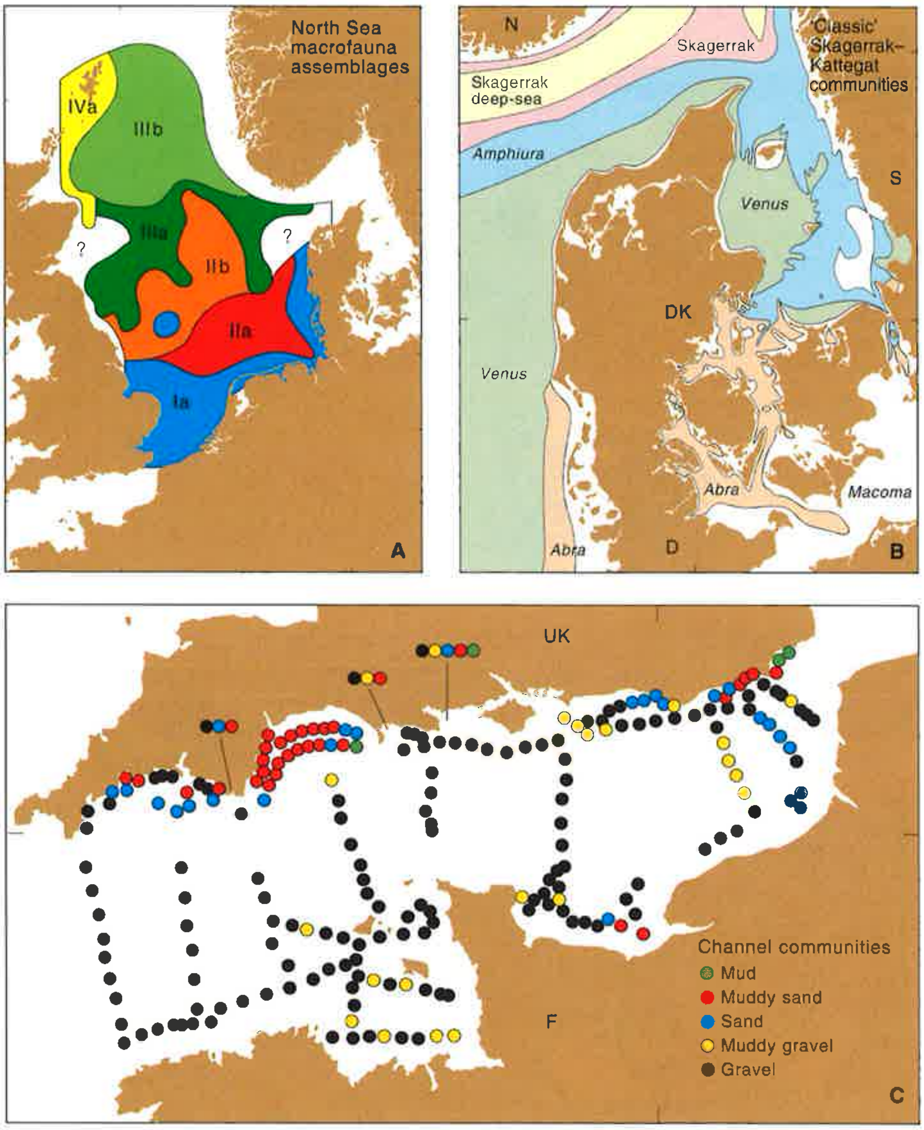

Figure 4·3. Benthos of the North Sea.

A: Distribution of some macrofauna assemblages in the North Sea. Source: Künitzer *et al.* (1992). Infauna assemblages of the subtidal North Sea, excluding the Channel, Skagerrak, and Kattegat:

A coastal assemblage in the southern North Sea and on the Dogger Bank at depths shallower than 30 m (group Ia, 52 stations, 27 ± 8 species per station, 805 ind./m^2, 9.5 g organic weight/m^2).

An offshore assemblage on fine sand at 40–70 m depth in the central North Sea (group IIb, 61 stations, 43 ± 10 species per station, 1093 ind./m^2, 7.6 g organic weight/m^2), and a similar offshore assemblage (group IIa, 40 stations, 44 ± 9 species per station, 1995 ind./m^2, 12.6 ± 7.5 g organic weight/m^2) in the southern North Sea, on muddy sand at 30–50 m depth.

An offshore assemblage occurring deeper than 100 m in the northern North Sea (group IIIb, 41 stations, 51 ± 13 species per station, 2863 ind./m^2, 3.5 g organic weight/m^2), and an offshore assemblage at 70 to 100 m water depth in the central North Sea (group IIIa, 46 stations, 54 ± 16 species per station, 1224 ind./m^2, 7.4 g organic weight/m^2).

A northwestern offshore assemblage in the region of the Orkney-Shetlands and off the Scottish coast (group IVa, 12 stations). The two northern North Sea assemblages IIIa and IVa have many indicator species in common that do not occur in the shallower areas of the southern North Sea.

B: Distribution of 'classic' communities in the Skagerrak-Kattegat area. Source: after Thorson (1979), and Petersen (1914).

C: Distribution of some macrofauna communities in the Channel. Source: Holme (1966). Few studies extend to the offshore areas of the Channel. The most detailed is that undertaken by Holme (1966), who sampled 311 stations by anchor dredge throughout the Channel. He identified five offshore animal communities:

- muds with the echiurid *Maxmulleria lankesteri* and the bivalve *Saxicavella jeffreysi*
- muddy sands with *Echinocardium cordatum*, *Amphiura filiformis*, and *Abra alba*
- sands with *Venus striatula*, *Echinocardium cordatum*, and *Acrocnida brachiata*
- muddy gravels with *Upogebia* sp., *Nucula nucleus*, and *Venus verrucosa*
- gravels with *Nucula hanleyi*, *Venerupis rhomboides*, etc. Often associated with beds of the brittle star *Ophiothrix fragilis* on harder ground

In shallow waters were found:

sands with *Arenicola marina*, *Nephtys* sp., *Tellina tenuis*, etc.

muds with *Macoma balthica*, *Cerastoderma edule*, *Nereis diversicolor*, etc.

Zoobenthos assemblages: distribution, biomass, and diversity

a) North Sea excluding the Channel, the Skagerrak, and the Kattegat

Large-scale subregional differences in the benthos of the North Sea have been demonstrated by modern studies following the pioneering work by C.G.J. Petersen, who estimated potential fish food in Danish waters in the beginning of the century (Petersen, 1914). In the spring of 1986 the International Council for the Exploration of the Sea (ICES) organized a comprehensive survey of the North Sea (excluding the Channel, the Skagerrak, and the Kattegat) (Künitzer *et al.*, 1992) covering the macrofauna, the meiofauna, and the epifauna. The survey did not cover inshore coastal areas of the North Sea or the Wadden Sea, but gave good coverage of the central and northern North Sea. The description that follows is based on results of the survey.

Macrofauna

The main patterns of macrobenthic species distributions showed that the bottom fauna of the North Sea consist of cosmopolitan species (northern elements) whose southern limit lies north of the Dogger Bank, and southern elements whose northern limit is the 100 m contour (see Figure 2·1). Northern and southern species mix in the central North Sea, and northern and southern assemblages overlap along the 70 m contour. It is possible that the separation of the macrobenthic infauna into northern and southern components along the 70 m contour is a result of the current pattern in the North Sea (see Chapter 2). Figure 4·3A shows assemblages of species representative of different areas of the North Sea. Assemblages resembling those of deep-sea areas occurred at depths greater than 200 m along the shelf edge of the North Sea (with deepwater corals of the genus *Lophelia*) and in the Norwegian Trench and the Skagerrak. The distribution of species also appeared to be determined by the sediment type. In a model using chlorophyll-*a* content and median grain size as predictors in addition to latitude, sediment characteristics accounted for most of the variance. In areas where macrobenthos assemblages were apparently determined by different water masses, the sediment may have been less important in structuring the assemblages. Total abundance showed a weak gradient with latitude. There was a tendency for density to increase towards the north. The average number of species per assemblage gradually increased with depth, ranging from fewer species in assemblages in water shallower than 30 m (group Ia) through median numbers of species in assemblages at 30–70 m depth (groups IIa and IIb) to the maximum recorded among assemblages in areas deeper than 70 m (groups IIIa and IIIb). Towards the Scottish coast (group IVa), the number of species decreased again. In northern areas, diversity (the number of species versus the number of individuals) was considerably higher than elsewhere. In addition to latitude, both depth and longitude (which are highly correlated in the North Sea, running along a slight southeast to northwest gradient) showed a correlation with increasing diversity. Other environmental variables that were measured had no clear influence on diversity.

Total biomass showed a clear and significant trend with latitude: at northern latitudes biomass decreased considerably. The main shift was not caused by one major taxonomic group overtaking another moving northwards. Rather, the same trends seemed to be operating within the different groups. Apart from latitude, sediment composition and chlorophyll-*a* content of the sediment also significantly influence both total biomass and the biomass of most separate groups. Biomass increased with silt contents between 0.1 and 1%, remained relatively uncorrelated for silt contents between 1 and 10%, and decreased with silt contents for very fine sediments (silt content > 10%). Mean weight per specimen also showed a very clear gradient with latitude. In areas to the north, with increasing depth, individual size became considerably smaller. The variation in mean biomass per assemblage was very high. Mean biomass was lowest in the northern North Sea (groups IIIb and IVa). The biomass increased towards the shallower southern North Sea and reached the highest values south of the Dogger Bank (groups Ia and IIa).

Meiofauna

At nearly all stations, nematodes were the dominant meiofauna group (Huys *et al.*, 1992). Densities ranged from 60 to 4200 ind./10 cm^2, with an average over all stations of 760 ind./10 cm^2. Nematodes became especially dominant at about 54°N, although there was no trend in their density with latitude. Only in the Southern Bight were copepods sometimes the dominant group. The fact that there is almost an order of magnitude of difference in diversity between the Southern Bight and the rest of the North Sea is linked with specific conditions in the area. It should be noted, however, that the nematode/copepod ratio varied considerably in the central and northern North Sea. Although this ratio is difficult to interpret, it suggests that nematodes and copepods are independently influenced by a complex suite of environmental parameters. Copepod density and diversity decreased with increasing latitude. The highest value was 181 ind./10 cm^2 in the Southern Bight against a minimum of 18 ind./10 cm^2 in the Norwegian Trench. Biomass decreased northwards until 57°N, but then increased again.

Epifauna (including shellfish)

Four assemblages can be distinguished in the northern North Sea, determined by depth and sediment characteristics. For example, Norway lobster (*Nephrops norvegicus*) and pandalid shrimps occur in deeper waters with appropriate sediments. Because of the greater influence of depth on epifaunal assemblages, the epifaunal communities appear to reflect hydrographic subdivisions of the North Sea. In summer, North Sea epifauna can be divided into two main clusters, one situated to the north and one to the south of the Dogger Bank. The epifauna on the Dogger Bank and in the central North Sea are dominated by filter-feeding species, in contrast to the scavenging or predating epibenthic species in the southern North Sea, which may reflect different ways in which energy is transferred through the benthic system. In winter the epifauna can be divided into a western cluster and an eastern cluster.

b) Kattegat and Skagerrak

In the Kattegat and Skagerrak (Figure 4·3B), the first quantitative investigations of marine soft-bottom benthos were made in the beginning of the century by Petersen. This work was later completed by mapping benthic communities in several parts of the area. Petersen's data were also reanalysed using modern multivariate techniques. The basic distribution of fauna is such that the shallower sandy-mud bottoms of the Kattegat are dominated by a typical '*Macoma* community', which grades into *Amphiura* spp. in deeper and more muddy sediments. In the Skagerrak, above 200 m, a typical '*Abra-Amphiura* community' prevails, with an average biomass of around 100 g Ash-Free Dry Weight (AFDW)/m^2. In the deeper basins (over 600 m in some places) typical dominant species are the polychaete *Spio* sp., *Chaetopterus variopedatus*, and the bivalve *Keliella*

Box 4·4. *Long-term changes in macrotidal estuaries*
The benthic animals living in macrotidal (tidal range up to 12 m in the Channel) estuaries are adapted to extreme temperatures, wave impact, sunlight, the tidal water regime, and the dilution of sea water by fresh water. Exposure to the atmosphere and the effect of tidal currents, storms, severe winters, and hot summers have been shown to operate as important regulating factors in the succession of the dominant species over time. Their distribution depends greatly on their capacity to control the osmotic pressure of body fluids (osmoregulation) and on sediment characteristics. Similar assemblages of animals are found in the various estuaries around the Channel in response to these two environmental parameters. Recent changes in the estuarine environment may be assessed by studying the relative size of the areas occupied by such assemblages for a specific type of sediment. From 1978 to 1990, the crustaceans *Eurydice pulchra* and *Haustorius arenarius* immigrated into several Channel estuaries together with marine sediment. At the same time, silting has been increasing on higher tidal levels where salt-marsh plants (*Spartina* spp.) have expanded. The result is continued shrinking of the true estuarine areas where the highest biomass of macrofauna (*Cerastoderma edule*, *Nereis diversicolor*) is currently found. It has also been shown that nutrient enrichment has indirectly facilitated the presence of opportunistic species such as *Pygospio elegans* which recolonized areas after benthos kills following anoxic conditions. The overall result of these successive changes is an impoverishment of the ecosystems.

sp., with other bivalves such as *Thyasira ferruginea*, *T. eumyaria*, *Yoldiella lucida*, and *Nucula turgida* also common. Below 200 m, biomass averages around 25 g AFDW/m^2. Because of the differences in bathymetry, there is little similarity between the fauna found respectively in the Skagerrak and the North Sea.

c) Channel

In the Channel (Figure 4·3C), infralittoral sands and their fauna extend down to approximately 20 m depth and are largely confined to a narrow band along the coast (Holme, 1966). A highly productive *Venus fasciata* community, dominated by molluscs, characterizes the coarse sands in the region between Normandy and Brittany, with mean biomass values reaching 51 g AFDW/m^2. In embayments off the coast of the United Kingdom and in French estuaries, muds down to 20 m depth are characterized by a *Macoma balthica* community, with very high densities of associated species reaching a biomass of 40 g AFDW/m^2 and more. Epifauna on the continuous coarse sediment deposits that extend from the Atlantic to the Strait of Dover show a correlation between the eastern limits of penetration of numerous species into the Channel and temperature gradients. In the reverse direction, there has been a penetration of species from the North Sea into the eastern Channel. The 70–80 m isobath marks a further division into coastal and open-sea fauna. In water deeper than 70 m, flats with gentle gradients are covered with species living on boulders or pebbles with developed epifauna on coarse, shelly sand. Very limited information is available on the meiofauna in the Channel.

d) Intertidal environments

Extensive shallow intertidal areas are found in estuaries (Box 4·4) and along rocky shores and sandy beaches. Soft bottoms also cover large areas of the Wadden Sea. As with the subtidal fauna, biomass increases with sediment fineness up to a certain point, reflecting the influence of physical and chemical factors and available organic matter. Fauna are poorer on exposed beaches than in sheltered areas such as the muddy Wadden Sea and sea-grass beds, which are rich in organic matter. For example, in the Dutch part of the Wadden Sea the biomass of intertidal fauna is highest in well-oxygenated muddy sands (42 g AFDW/m^2), lower in muds (18 g AFDW/m^2), and lowest in clean sands (13 g AFDW/m^2).

Commercial bivalves such as the cockle (*Cerastoderma edule*) and the blue mussel (*Mytilus edulis*) are found in intertidal or shallow subtidal areas. Scallops (*Pecten maximus*), crabs, lobsters, and crangonid shrimps are also found in inshore waters. The abundance of bivalves and shrimps varies greatly in relation to recruitment.

Distribution of phytobenthos

The distribution patterns of macroalgae also indicate that the North Sea is a transition area between the warm-temperate region in the southwest, and the cold-temperate region in the east and in the north. A number of salt-marsh plants reach their northern limit of distribution in the Firth of Forth and their eastern limit of distribution on the Dutch coast. During recent decades a number of species of plants have extended their range of distribution northwards and eastwards. For example, the Japanese weed *Sargassum muticum*, which was introduced to southern England in 1973, had reached the Norwegian part of the Skagerrak by 1986.

Superimposed on the effects of temperature and exposure mentioned above are local variations. Numbers of brown and red algae are reduced in the lower salinity waters of estuaries which appear to favour green algae such as *Cladophora* spp., *Enteromorpha* spp., and *Blidingia* spp. The type of bottom substrate (its mobility, hardness, and porosity) also influences the floristic composition of shores. For example, rapid erosion of chalk cliffs on the Kent coast prevents the long-term establishment of perennial algae. New artificial habitats, sea walls, embankments, and marinas have extended the local abundance and geographical range of a number of species. Some native macroalgal species are affected by competition with introduced species or are subjected to important fluctuations through episodic diseases of epidemic proportions. *Laminaria digitata*, *L. hyperborea*, *Ascophyllum nodosum*, *Fucus serratus*, and *Chondrus crispus* are harvested for commercial use. Deposits of calcareous algae (maerl) form a rare habitat with a rich associated fauna in the region between Normandy and Brittany, with more limited deposits in the Baie de Seine and Falmouth Bay.

Changes in North Sea benthos

a) Zoobenthos

Few long-term data sets on trends in the benthos of the open North Sea and the Channel existed in the late 1970s. Within the framework of the COST (Coopération Scientifique et Technique) 647 Programme of the European Economic Community, factors influencing variability in different geographical areas were investigated from the late 1970s onwards. Soft-substrate subtidal and intertidal systems have been the main subjects of collaborative studies (Souprayen *et al.*, 1992a and 1992b). Most of the time series are still too short to be of use, but interesting changes in benthos densities and biomass have been described.

The abundance and biomass of infauna have increased at most of the subtidal monitoring stations with muddy sands off the Northumberland coast (Austen *et al.*, 1991), on the Dogger Bank, and in the Southern Bight, the German Bight, the Skagerrak, and the Kattegat. For example, studies carried out in the 1970s and the 1980s showed a clear increase in biomass along the Swedish Skagerrak coast, in the open Kattegat, and in the Oslofjord. Stations first sampled in 1911–1912 were revisited in 1984. The ophiurid *Amphiura filiformis* had increased in numerical dominance at over 70% of the stations sampled. In general, ophiurids and annelids had increased in dominance, and the majority of species were found to be smaller in size than in earlier surveys.

In the western part of the Wadden Sea, biomass has doubled or tripled over the last 20 years. More than half of the species present contributed to this increase. Some significant changes in the composition of the macrozoobenthos were observed. The proportion of polychaetes increased at the expense of molluscs and crustaceans. Since about 1970, the polychaete *Heteromastus filiformis* has increased in abundance in several subtidal and intertidal sediments (in parts of the Wadden Sea and several estuaries of the Channel such as the Baie de Somme), where it has spread from its traditional muddy habitat to sandy sediments and established itself as a dominant species. In the northern part of the Danish Wadden Sea, an increase in macrozoobenthic biomass of dominant species was observed in the period 1980–1989. In the eastern Dutch Wadden Sea, which does not have a significant discharge of fresh water, no increase was found in macrozoobenthos.

Organic enrichment of muddy sediments, with high organic content, leads to an increase in macrobenthic biomass only up to a certain point. Sediments become anoxic when overloaded with organic matter, which then leads to the death of the benthos. In late summer of the years 1981–1983, 1986, and 1989, oxygen depletion was observed in the bottom water of some areas of the German Bight and off the Danish coast. Bottom fauna died and, in the following year, recolonization took place with pioneer species such as the polychaete *Spiophanes bombyx*. The oxygen deficits occurred after prolonged periods of water stratification when all oxygen in the water below the pycnocline had been used up by microbial and animal respiration without subsequent renewal by bottom currents.

Similar events have been reported from the southeastern Kattegat. Localized significant reductions of *Amphiura filiformis* were also related to hypoxia. Between 1983 and 1988 several dominant infauna species were wiped out. For instance, the trawl catches of Norway lobster (*Nephrops norvegicus*) fell from 10.8 kg/ha to nothing during the period 1984–1989.

In the intertidal area, anoxic conditions have also been reported. Small black areas have recently appeared on some sediment surfaces of intertidal flats in the German Wadden Sea, indicating the presence of anoxic conditions and causing the death of the interstitial fauna.

In order to assess the scale of the observed changes at some sites in the North Sea, data collected on benthos communities through the Monitoring Master Plan (MMP) of the North Sea in 1990–1991 were compared with data collected in 1986 by the ICES Benthos Ecology Working Group and fed into the same database. This preliminary comparison showed that the benthic assemblages seem in general to reflect natural variability within the North Sea, which should be taken into account when assessing anthropogenically induced changes in the North Sea. These changes may be different among the various assemblages. The general distribution of species and trends in biomass, diversity, and density may be explained by the following factors: current patterns and water masses, depth and stratification, surface productivity, sediment distribution and bottom shear stress, fisheries and other human impact, and the history of the North Sea. In other words, effects from anoxia appear to be localized and short-lived.

b) Phytobenthos

Several types of plants have apparently disappeared from stretches of the North Sea coast. Red macroalgae, for example, disappeared from the tidal creeks of the northern German Wadden Sea progressively up to the 1980s. On many North Sea coasts, eel grass (*Zostera marina*) was reduced drastically in the 1930s by the so-called wasting disease and was unable to recolonize the subtidal regions of the Wadden Sea. In the 1960s it also declined in other areas such as the Danish coast and the coast of Brittany. Together with the disappearance of the subtidal vegetation, the associated animals (snails, shrimps, pilefish) disappeared. In a review, Reise *et al.* (1989) summarize a number of possible causes for the changes in eel-grass distribution and abundance in the Wadden Sea. Some of the more recent declines have been linked to nutrient enrichment, which has led to decreased transparency and massive epiphytal growth. Reise *et al.* also suggest that declines in eel grass have coincided with a run of warm summers and mild winters. They conclude that the pattern of changes in distribution and abundance of eel grass is complex and that no definitive interpretation can be offered.

The toxic algal bloom of *Chrysochromulina polylepis* in the Skagerrak and Kattegat in May and June of 1988 resulted in direct drastic effects on both soft-bottom and hard-bottom organisms, from the surface down to at least 15 m. The most pronounced effects were observed in the hard-bottom habitats along the exposed coast, where for the first time macroalgae were observed to be affected by toxicity due to a phytoplankton bloom. Tissues of several red algae, but also brown and green algae, were bleached owing to inhibition of the chlorophylls. However, the effects appeared to be temporary (two to three months' duration).

Other types of phytobenthos, on the contrary, have increased dramatically in number in recent years. Prolific growth of the green algae *Ulva* spp. has occurred on a number of beaches on the north coast of Brittany (Piriou *et al.*, 1991) leaving algal deposits as high as 2 m at the strand line. These 'green tides' occur on sandy beaches with a gentle slope and large surface area, which have a slow turnover of water offshore and a large direct input of nitrogen. In the enclosed, shallow, mudflat-dominated Langstone Harbour on the English coast of the Channel, extensive growth of *Enteromorpha* spp. and *Ulva* spp. occurs. Accumulation of driftweed has been reported at a number of sites along the English coast of the Channel, which is believed to be caused by tidal current concentration. In the Wadden Sea, mass developments of green algae (including *Chaetomorpha* spp.) covering whole areas of tidal flats have occurred from May to September since 1989. In the Skagerrak, interesting successions of communities at fixed sites on coastal subtidal rocks regularly revisited since 1969 have been described by Lundälv *et al.* (1986). Filamentous red algae increased in 1971–1976, and at 5–10 m depth, a dense cover of the brown alga *Halidrys siliquosa* was shown to have declined in 1977, while mussels (*Mytilus edulis*) increased. In 1988 the common starfish (*Asterias rubens*) became abundant feeding on the dead mussels killed by *Chrysochromulina polylepis*. It has been suggested that an increase in phytoplankton density may have reduced the light penetration and water transparency in favour of the red algae. Large quantities have also been washed ashore in the Kattegat since the 1970s. The input of nutrients by man has been blamed (see Chapter 5), but recent studies have shown that some affected areas have recovered.

In other regions, no recent changes have been described in the macroalgal flora. At Helgoland, for instance, the dense *Laminaria hyperborea* forest and the deepest coralline crusts occupy the same levels in the 1990s (respectively, 4–8 m and 12–15 m) as they did in the 1960s.

Box 4·5. *Species alien to the North Sea*

Some alien benthic species and dates of introduction to the North Sea are:

1870 Marsh-grass (*Spartina anglica* syn. *townsendii*)
1887 Slipper limpet (*Crepidula fornicata*)
1890 Clam (*Petricola pholadiformis*)
1920 Chinese mitten crab (*Eriocheir sinensis*)
1937 Parasitic copepod (*Mytilicola intestinalis*)
1946 Barnacle (*Elminius modestus*)
1970 Pacific oyster (*Crassostrea gigas*)
1973 Japanese seaweed (*Sargassum muticum*) and kelp (*Undaria pinnatifida*)
1979 Razor shell (*Ensis directus*)
1981 Polychaete worm (*Marenzelleria viridis*)
1990 Algae (*Grateloupia doryphora* and *G. filicina*)

Alien species

In the course of the past century, various alien benthic species have found their way into the North Sea. A number of them are listed in Box 4·5. Some at least, for example *Crepidula fornicata*, cause problems and change the ecosystem.

Shipping creates another environmental risk: the spreading of exotic species by ballast water. This problem has been taken up as a subject of study by the International Maritime Organization (IMO). Most species of algae and fauna are killed either in transit or when the ballast water is discharged. Some, however, survive and can be a threat to native species.

Table 4·1. Twenty most abundant fish species in the North Sea in terms of biomass (thousands of tonnes), from analysis of survey records for the period 1977–1986. Source: Daan *et al.* (1990). The total estimated biomass of all species is ca. 12.3 million tonnes.

Demersal species	Biomass, 10^3 t	Pelagic species	Biomass, 10^3 t
Common dab (*Limanda limanda*)	2110	Herring (*Clupea harengus*)	1439
Haddock (*Melanogrammus aeglefinus*)	826	Sprat (*Sprattus sprattus*)	474
Cod (*Gadus morhua*)	670	Horse mackerel (*Trachurus trachurus*)	427
Whiting (*Merlangius merlangus*)	643	Mackerel (*Scomber scombrus*)	349
Saithe (*Pollachius virens*)	585		
Plaice (*Pleuronectes platessa*)	485	Not easily classified*	
Starry ray (*Raja radiata*)	308	Sandeels (mainly *Ammodytes marinus*)	1789
Long rough dab (*Hippoglossoides platessoides*)	227	Norway pout (*Trisopterus esmarkii*)	752
Grey gurnard (*Eutrigla gurnardus*)	206	Spurdog (*Squalus acanthias*)	175
Lemon sole (*Microstomus kitt*)	178	Blue whiting (*Micromesistius poutassou*)	84
Poor cod (*Trisopterus minutus*)	92		
Sole (*Solea solea*)	54		

* These species typically live within a few metres of the seabed but feed predominantly on organisms that live in the water column.

Fish

A total of 224 species of fish have been recorded in the North Sea, ranging in size from 5 cm gobies (*Pomatoschistus* spp.) to the 10 m basking shark (*Cetorhinus maximus*). Most of the common species are those typical of shelf seas, although deepwater species are found along the northern shelf edge and in the deepwater channel of the Norwegian Trench and the Skagerrak.

The species of fish found in the North Sea differ widely in abundance, and it is estimated that fewer than 20 species make up over 95% of the total fish biomass. As in other areas, North Sea fish can be broadly classified into pelagic and demersal species, i.e., those that typically live in mid-water and those that live in association with the seabed, respectively (Box 4·6). Based on international surveys, the most abundant species in the North Sea are listed by category in Table 4·1. Many of these species are the object of commercial fisheries, but some that are not normally landed in large quantities, such as the common dab, may be equally abundant (Figure 4·4).

Within the North Sea different depth zones and bottom substrate types tend to have different assemblages of demersal fish species. Two assemblages typified by different relative abundances of saithe, haddock, cod, Norway pout, whiting, and blue whiting in northern and central areas give way to an assemblage typified by common dab, whiting, grey gurnard, plaice, cod, horse mackerel, and sandeels in southern and eastern areas (Figure 4·5).

The spawning grounds of fish that spawn their eggs in the water column (as most species do) are widely distributed over the North Sea. Fish whose eggs adhere to the substrate, e.g., sandeels (*Ammodytes marinus* and *Hyperoplus lanceolatus*) and herring (*Clupea harengus*), use spawning grounds that are more localized and that are determined by the availability of the appro-

Box 4·6. *Fish classification*

The terms that are used to group or classify fish are often confusing since the classifications may be based on different criteria and may overlap with one another.

Scientifically, fishes, like other animals, are classified to Class, Order, Family, Genus, and Species. The two major classes are the Selachii (sharks, rays, and rabbit-fishes) and the Pisces or Ostichthyes (bony fishes). Representative examples of families with numerous species in the North Sea are Rajidae (rays) and Gadidae (cod fishes).

Fishes inhabiting the water column are called *pelagic fish*, while those living on or near the bottom are *demersal fish*. This classification is convenient, particularly in relation to the fisheries, as pelagic fish are mostly caught by gear like purse seines and drift nets, while demersal fish are most often taken in bottom trawls. Some species, however, are pelagic during the earliest stages of life and later become demersal. Others may shift seasonally, as they feed, for example, on plankton in the upper water layers in summer and on bottom organisms in winter.

The terms *flatfish* and *roundfish* originate from commercial use, particularly in the United Kingdom. Flatfish include many types of species such as turbot (*Psetta maxima*), plaice (*Pleuronectes platessa*), common dab (*Limanda limanda*), halibut (*Hippoglossus hippoglossus*), and sole (*Solea solea*). Roundfish, however, are generally understood to mean gadoids, i.e. fish belonging to the cod family: cod (*Gadus morhua*), whiting (*Merlangius merlangus*), pollack (*Pollachius pollachius*), saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*), etc.

By definition the term *whitefish* refers to the family Coregonidae, which are freshwater fish found in lakes of Northern Europe. In relation to the North Sea, however, the British meaning of whitefish is all commercially important marine fish, except salmon (*Salmo salar*), herring (*Clupea harengus*), and mackerel (*Scomber scombrus*).

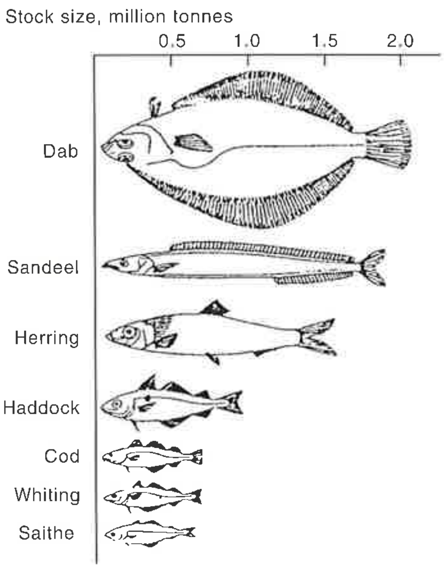

Figure 4·4. Estimates of the fish biomass of the North Sea. Source: Daan *et al.* (1990).

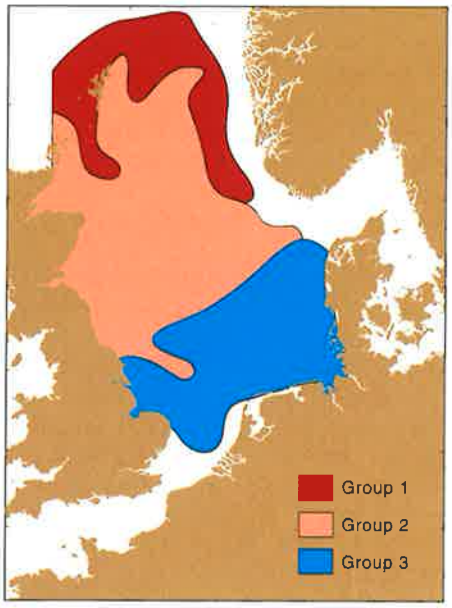

Figure 4·5. Typical North Sea fish assemblages, with species in order of abundance. Source: Daan *et al.* (1990). Refer to Table 4·1 for Latin names of species.

Group 1: Slope edge association: saithe (44%), haddock (12%), Norway pout (11%), whiting (9%), blue whiting (4%), cod (4%), other (16%).
Group 2: Central North Sea: haddock (42%), whiting (14%), cod (9%), Norway pout (5%), saithe (4%), other (26%).
Group 3: Southeastern North Sea: dab (22%), whiting (22%), grey gurnard (13%), plaice (6%), cod (6%), other (31%).

priate habitat. Herring, for example, require well-oxygenated gravel beds that are found in tidally energetic areas in the Channel, between the Orkneys and Shetlands, along the east coasts of Scotland and England, and off southern Norway.

The dispersal of fish larvae until their metamorphosis into small fish at an age of approximately 1–7 months after spawning, depending on species, is determined largely by the pattern of water circulation. As the small fish develop, however, they may concentrate in more localized nursery areas. The shallow coastal margin, especially in the southern North Sea, is an important nursery area for juveniles of many fish species while different areas are important for some other species. Figure 4·6 shows catch rates, indicative of geographical distribution, for six species of young fish in the North Sea.

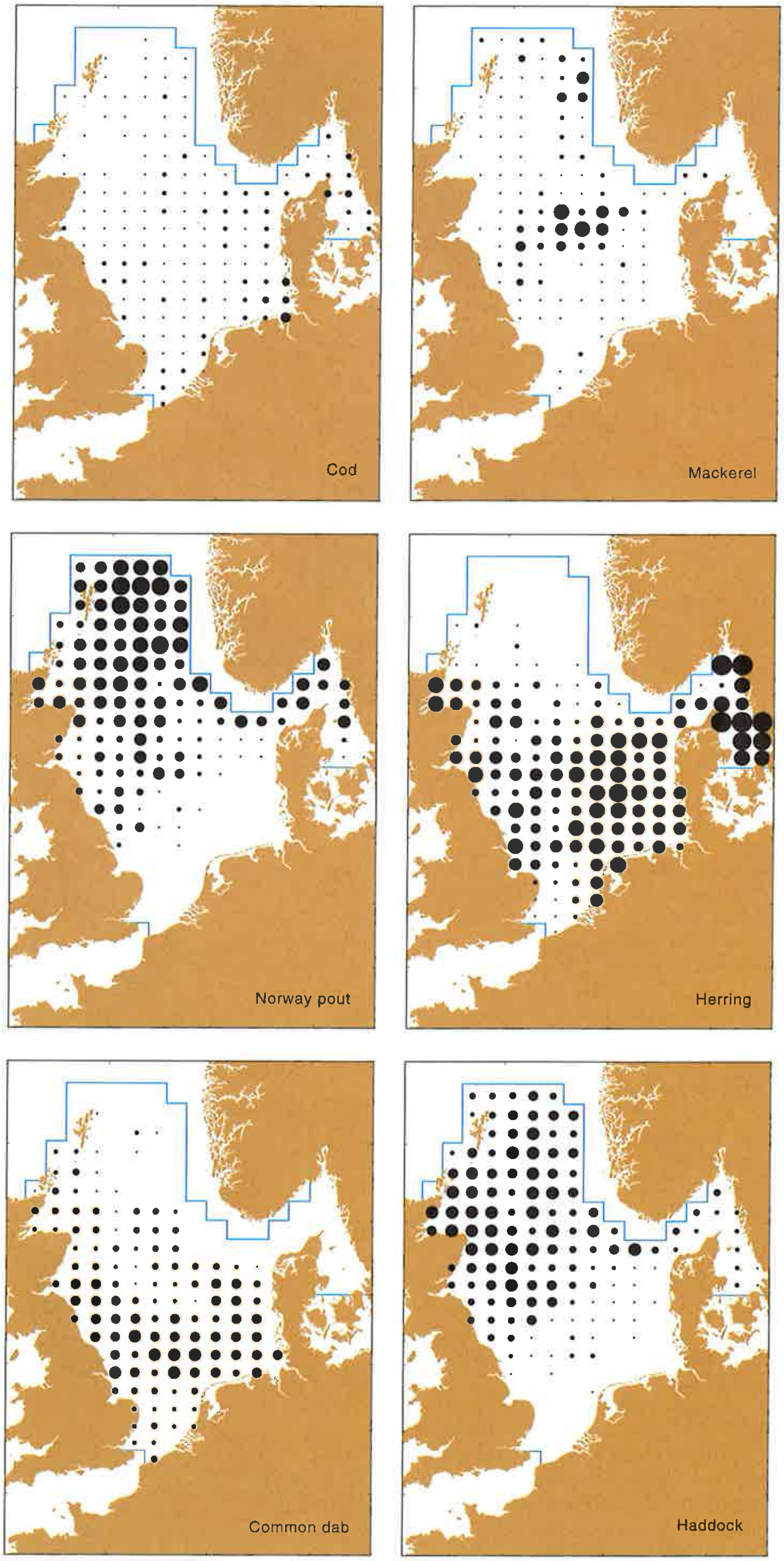

Figure 4·6. Catch rates of 1-group fish (<3 years old in the case of common dab) from the International Young Fish Survey in February, averaged over the years 1983–1987 (except mackerel: 1960–1987, and common dab: 1985). Catch rates are numbers per 10 h fishing for cod and mackerel, and numbers per hour for other species. Source: Daan *et al.* (1990).

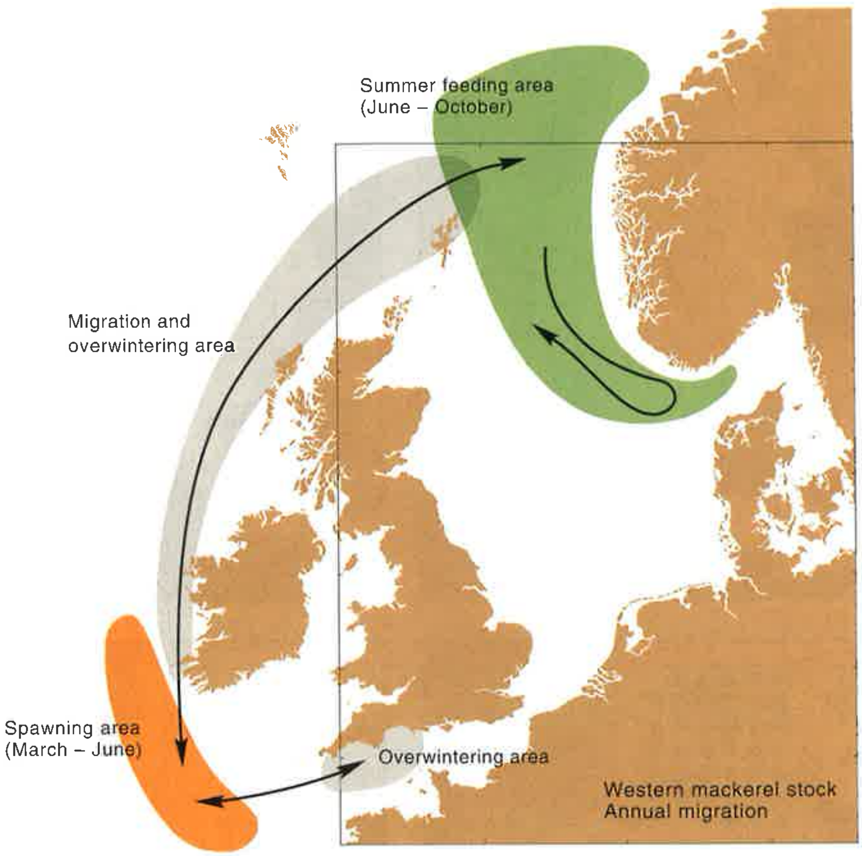

Figure 4·7. General pattern of the annual migration of the Western mackerel stock to the North Sea from spawning grounds along the continental slope. Source: ICES (1990).

Some fish species migrate between the North Sea and adjacent areas, notable examples being mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*), which migrate annually to the North Sea from spawning grounds along the continental slope to the west (Figure 4·7). In addition, herring migrate within the North Sea, while adult herring that spawn in the Baltic Sea migrate westwards as far as the eastern North Sea after spawning in spring, and then return in autumn.

Research is in progress to evaluate changes in the abundance of less common species in the North Sea. Studies of commercial fish landings at a port in the Netherlands indicate that catches of a number of species of fish have decreased over the last few decades. These include two species of dogfish (*Scyliorhinus canicula* and *Mustelus mustelus*), rays (Rajidae), conger eel (*Conger conger*), sturgeon (*Acipenser sturio*), and allis shad (*Alosa alosa*) (Bergmann *et al.*, 1991; de Vooys *et al.*, 1991). In addition, the greater weever (*Trachinus draco*) now appears to be locally extinct in the area close to the Dutch coast where the catches are made. Because these studies are dependent on an incentive scheme for reporting catches of rare fish and because fishing areas and practices may have changed, it is difficult to evaluate the extent to which decreases reflect a real decrease in abundance. The species concerned, moreover, are mainly species that are widely distributed in the North Sea and adjacent waters. It is therefore difficult to interpret the significance of, and reasons for, the observed changes.

A number of factors influence the abundance of fish stocks in the North Sea. Most of the demersal species exploited commercially in the North Sea are subject to fishing mortality rates that are among the highest recorded (ICES, 1993a). For cod and haddock, more than half the population present at the start of a year is caught during the same year. High fishing mortality combined with poor recruitment of young fish to the population has decreased some stocks to levels giving cause for considerable concern. The ICES Advisory Committee on Fishery Management has repeatedly advised a reduction in fishing effort on these stocks in the last few years (ICES, 1993a). In the case of herring, the stock was reduced to such a low level

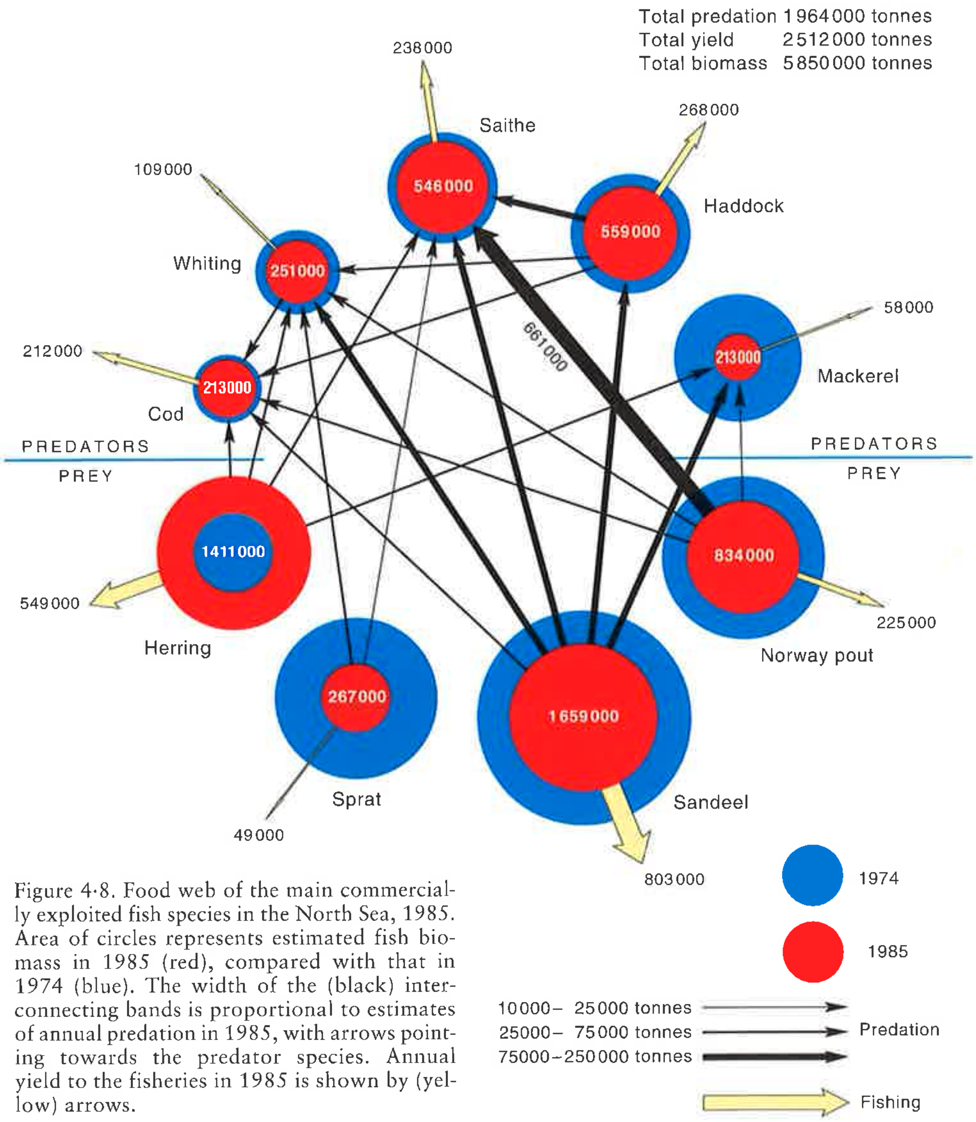

Figure 4·8. Food web of the main commercially exploited fish species in the North Sea, 1985. Area of circles represents estimated fish biomass in 1985 (red), compared with that in 1974 (blue). The width of the (black) interconnecting bands is proportional to estimates of annual predation in 1985, with arrows pointing towards the predator species. Annual yield to the fisheries in 1985 is shown by (yellow) arrows.

that a closure of the herring fisheries was implemented from 1977 to 1982.

There is considerable variation in the annual recruitment of young fish to the stocks (recruitment means the number of fish that reach a particular age – for example, one year old – each year). The extent of this variation depends on the species concerned. In plaice, for example, recruitment is fairly stable from year to year, whereas for haddock the largest year classes can be 200 times larger than the smallest. This variation in recruitment is largely due to variation in survival during the first year or so of life and has a considerable impact on the size of stocks in any given year.

The causes of annual differences in survival are difficult to establish. However, it is likely that variation in mortality rates due to predation, and variation in the pattern of larval dispersal from the spawning grounds, both play an important role in the survival of the larvae and young fish. A link has been postulated between changes in recruitment to the herring and sprat stocks and in the migration pattern of mackerel on the one hand, and an environmental anomaly in the Northeast Atlantic during the mid-1970s on the other (Corten, 1986). Supporting evidence for such a link has recently been published showing a decrease in the inflow of Atlantic water to the North Sea at this time (Svendsen and Magnusson, 1992). Over the last half century there have been major changes in plankton communities in the North Sea that may also be implicated in the changes in fish stocks (CPR Survey Team, 1992).

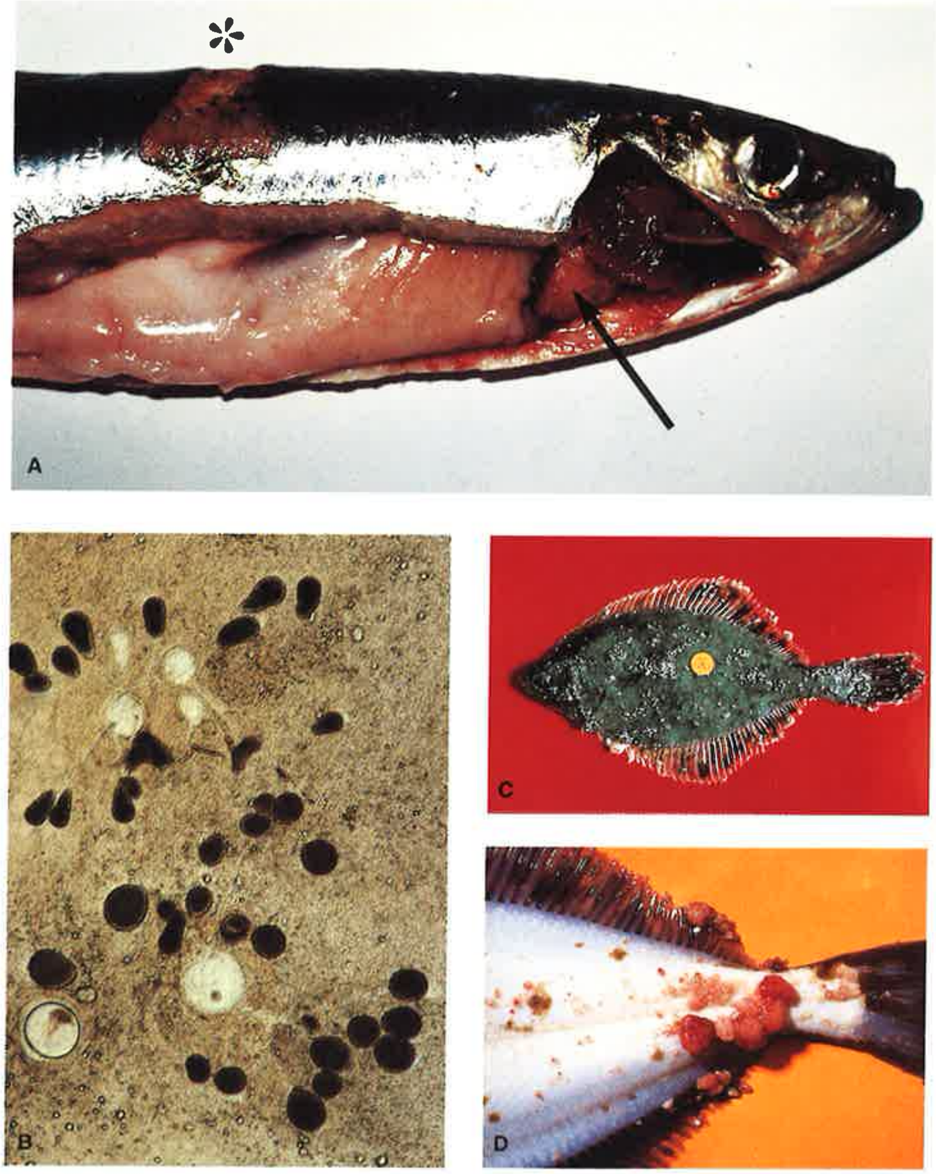

Figure 4·9. Examples of some fish diseases. Source: A and B, IMR, Lysekil, Sweden; C and D, Thalassa Picture Services.

A: Macroscopic signs of *Ichthyophonus hoferi* infection in herring: the arrow points to enlarged heart with white nodules; the asterisk shows a skin ulcer.

B: Hyphal (dark bodies) development of *Ichthyophonus hoferi* in the heart of herring as seen in a light microscope.

C and D: *Lymphocystis* in flounder.

In some cases, e.g., North Sea herring, a relationship has been suggested between recruitment and the size of the adult stock that produced those recruits (e.g., review by Bailey and Steele, 1992). As a result of the marked reduction in the spawning stock of North Sea mackerel (ICES, 1992), the production of eggs in 1986 is estimated to have been only 2% of that in the mid-1960s. Thus, it cannot be ruled out that the fisheries themselves have had a direct effect on recruitment through their effect on the spawning stock.

North Sea fish also interact with other marine organisms. One of the principal types of interaction is predation. Many top predators, including marine mammals and many species of seabirds, depend on fish, but by far the most important natural predators on fish are other fish (Figure 4·8). Fish are also subject to infection by diseases and parasites, and there are sporadic reports of mortalities caused by, for example, the fungus *Ichthyophonus* sp. (Figure 4·9) or the toxins associated with paralytic shellfish poisoning. However, occurrences of mass mortality due to such causes are normally local and transitory in nature.

Data from extensive trawling surveys and commercial catch information indicate that the average total fish biomass in the North Sea is around 12 million tonnes (Table 4·1). Estimates of the total annual production of fish (the quantity of new fish produced by growth and spawning each year) in the North Sea vary between five and ten million tonnes. Approximately three million tonnes are taken annually by the fishery, with natural factors (notably predation) accounting for the remaining losses.

Scientific investigations of fish in the North Sea have a history of about one hundred years. Serious concern about the fisheries, notably the North Sea fisheries for flatfish, was expressed during the last twenty years of the nineteenth century. Much of our present knowledge about fish is based on the commercially important stocks of flatfish (plaice and sole), roundfish (cod, haddock, whiting), pelagic fish (herring, mackerel, and sprat), and industrial fish (sandeel, Norway pout) species. Surveys carried out over the last twenty years, however, have provided information on the distribution and abundance of other less well-studied species. Studies of littoral and sublittoral fish communities have also been carried out on a more local basis.

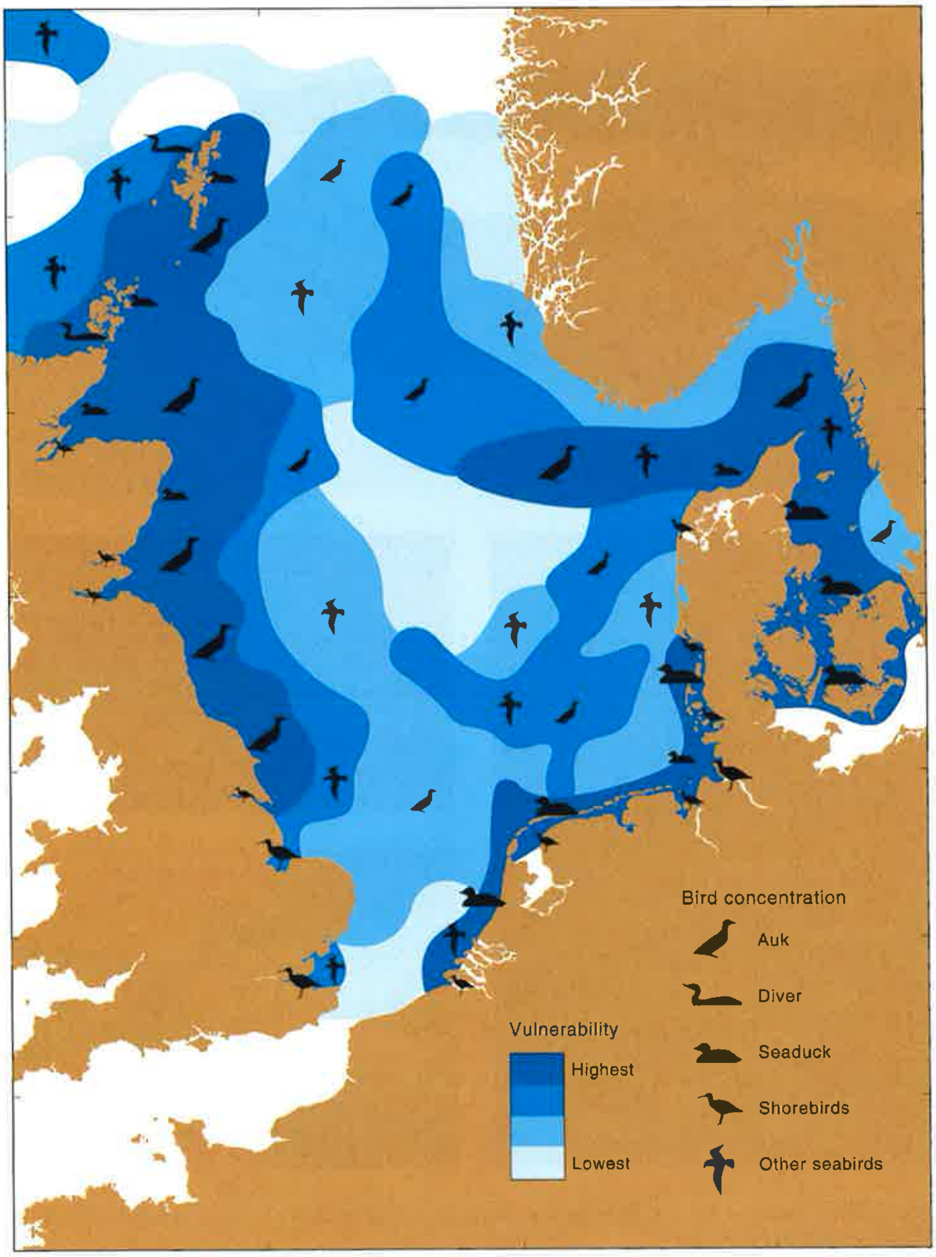

Figure 4·10. Vulnerability of bird populations in the North Sea to surface pollutants (mainly mineral oils) in August. The strength of the shading indicates the level of vulnerability, the bird silhouettes indicate the type of bird in the vulnerable concentration, and the size of the silhouette indicates the scale of importance of the bird concentration. Source: Carter *et al.* (1993).

Table 4·2. Numbers of common seabirds breeding in coastal areas of the North Sea. Source: Dunnet *et al.* (1990). Counts are of pairs, except for guillemot, puffin, and razorbill, which are counted singly.

Species	Number
Kittiwake (*Rissa tridactyla*)	420 000
Guillemot (*Uria aalge*)	680 000*
Fulmar (*Fulmarus glacialis*)	310 000
Herring gull (*Larus argentatus*)	250 000
Black-headed gull (*Larus ridibundus*)	140 000
Puffin (*Fratercula arctica*)	230 000*
Arctic tern (*Sterna paradisaea*)	77 000
Common gull (*Larus canus*)	76 000
Common tern (*Sterna hirundo*)	72 000
Lesser black-backed gull (*Larus fuscus*)	53 000
Gannet (*Morus bassanus*)	44 000
Razorbill (*Alca torda*)	73 000*

*number of individuals.

Birds

Some ten 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. In broad terms, seabirds move southwards or towards the coasts in winter, and northwards and offshore again in summer.

In addition to the seabirds, many shorebirds, such as wading birds and ducks, feed on mud flats and sand flats or other intertidal areas along the coast. The southern shores have favourable conditions due to the large tidal amplitude and relatively mild climate, which prevent the mud flats from freezing for most of the winter. The Wadden Sea is of particular importance both for breeding bird populations and for migratory birds. Six to 12 million birds of more than 50 different species utilize the Wadden Sea at many times of the year. Coastal waters of the United Kingdom are also of importance as wintering and migratory staging areas for waterfowl, particularly when waters on the eastern shores of the North Sea freeze.

An offshore and an inshore group may be identified among the seabirds. The offshore group includes members of several families, most notably the 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. Inshore birds include the seaducks, divers, cormorants, and terns. Some gull species and the black guillemot (*Cepphus grylle*) are also included in this group. These birds normally live within sight of land.

Many of the seabirds of the North Sea 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 biogeographic populations of common terns (*Sterna hirundo*) and great skuas (*Catharacta skua*), and a further 12 species are present in numbers exceeding 10% of their biogeographic populations (Table 4·2).

Most seabirds are predators at or near the top of food chains. The majority eat fish both live and as discards and offal, some feed on benthos, and a few consume zooplankton. Few data exist on seabird diets in quantitative terms.

Seabirds are generally characterized by high annual survival rates (long lifespans), delayed maturity, and relatively low reproductive rates. This results in slow population changes and survival of adults even during periods of low abundance of suitable food (Figure 4·10).

Counts of bird populations breeding on United Kingdom coasts indicate an increase in number during recent decades (Figure 4·11), and in some cases,

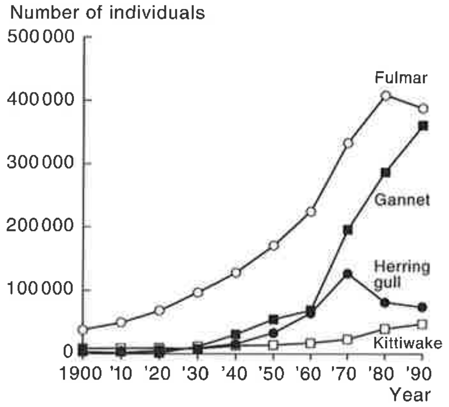

Figure 4·11. Changes over time in selected bird populations of the North Sea. Source: ICES (1994).

an expansion of range. Between 1969/1970 and 1985/1986 fulmar (*Fulmarus glacialis*), gannet (*Morus bassanus*), lesser black-backed gull (*Larus fuscus*), and guillemot (*Uria aalge*) increased by about 100%, while great skua and Arctic skua (*Stercorarius parasiticus*) increased by 150 and 220%, respectively. During the same period some species, e.g., roseate tern (*Sterna dougallii*), herring gull (*Larus argentatus*), and black-headed gull (*Larus ridibundus*), declined. In other areas, such as the Wadden Sea, the majority of the changes are increases.

Mammals

Estimated numbers of seals and harbour porpoises in the North Sea are shown in Table 4·3.

Seals

Two seal species breed along the coasts of the North Sea: the common or harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*) (Figure 4·12). Occasionally, stray ringed seals (*Phoca hispida*) and harp seals (*Phoca groenlandica*) are observed. In 1988, phocine distemper virus (PDV) led to major mortality among, mainly, harbour seals and, to a lesser extent, grey seals in the North Sea region (a total of approximately 16 000 seals), raising questions about the subsequent viability of the affected populations, and whether it would be possible to detect a relationship between the burden of contaminants, the health of stocks, and viral attack. Although there has been no conclusive evidence of an association between environmental contamination and the extent and severity of the epidemic, concern has been expressed that one may exist because evidence is accumulating from studies of other mammalian species about the potentially detrimental effects of organohalogens on reproduction and resistance to disease.

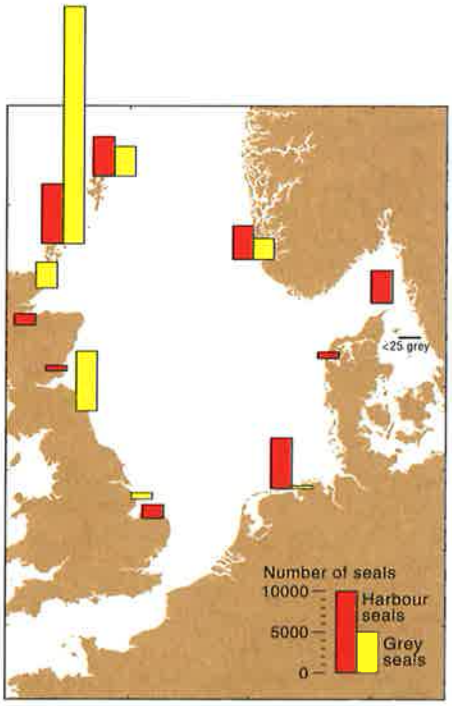

Figure 4·12. General distribution of the harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*) in the North Sea.

Although the harbour seal is one of the most widely distributed seal species in the world, the North Sea contains around 10% of the world population. The North Sea population of harbour seals is approximately 28 000. Broadly speaking, the harbour seal frequents estuaries and coasts where offshore banks and rocks are exposed at low tide. Diet, important in relation to transfers in the food chain, appears to vary according to the abundance of prey species. For example, an investigation in the Cromarty Firth, Scotland, illustrates that the seals switched from clupeids in 1988/1989 to gadoids and sandeels in 1989/1990, and shows a general increase in cephalopod prey from 1988 to 1991. Seasonal and yearly changes in the diet reflect changes in the local abundance of different fish species. Feeding sites also change. In the Wadden Sea area the harbour seal prefers flatfish species. The peak in pupping of the harbour seal usually occurs in late June, but may vary seasonally and geographically.

In the northern North Sea there is no evidence of population change in Norway or at Orkney, Scotland. In the Oslofjord, the area of Norway most affected by the 1988 disease outbreak, there were 102 harbour seals, including 26 pups, in 1991. At Shetland, the latest count (1991) is much lower than expected in relation to the previous count in 1984, but it is not clear if this

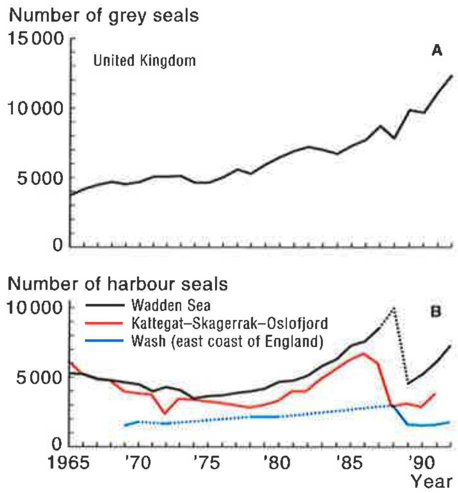

Figure 4·13. Long-term trends in seal populations.
A: Estimates of pup production for grey seal (*Halichoerus grypus*) breeding sites on the North Sea coast of the United Kingdom. Source of data: Sea Mammal Research Unit (UK).
B: Number of harbour seals (*Phoca vitulina*) in the North Sea, excluding Scotland and the west coast of Norway for which no detailed time series are available.

Table 4·3. Estimated numbers of seals and harbour porpoises in the North Sea in 1991. Source: ICES (1993b).

		Estimated number
Harbour seal (*Phoca vitulina*)		
Norway	Entire coastline	4 200
United Kingdom	Orkney/Shetland	12 000
	East Scotland	1 800
	East England	1 800
Wadden Sea		6 090
Danish Limfjord		750
Kattegat/Skagerrak		3 900
Grey seal (*Halichoerus grypus*)		
Norway	Entire coastline	4 200
United Kingdom	North Sea	43 600
Wadden Sea		250
Kattegat		< 25
Harbour porpoise (*Phocoena phocoena*)		
Northern North Sea		82 600

Table 4·4. Maximum numbers of harbour seals counted in the Wadden Sea area, 1987–1992. Source: Common Wadden Sea Secretariat.

Year	Denmark	Schleswig-Holstein	Nieder-sachsen	Netherlands	Total
1987	1400	3793	2245	1054	8492
1988*					
1989	870	1750	1400	535	4555
1990	1048	1974	1620	559	5201
1991	1097	2313	1924	750	6084
1992	1168	2861	2255	960	7244

*Data for 1988 are unreliable, owing to mortalities associated with the phocine distemper virus.

is due to a real decline or to a change in the haul-out (coming out of the water onto rocks or beaches) behaviour of the seals. For the rest of the North Sea, the population in 1991 was approximately 14 000 seals. At reference sites in eastern Scotland and eastern England the population was not affected by the epidemic. In contrast, the Wadden Sea harbour seal population was reduced from 10 000 before to 4000 individuals after the epidemic. From 1989 to 1992 the population recovered to some 7000 animals (Table 4·4). Seal numbers have also increased markedly in the Kattegat/Skagerrak, fulfilling recovery predictions made on the basis of changes in age structure following the 1988 disease outbreak. On balance, therefore, harbour seal populations have either not changed or have increased since 1988 (Figure 4·13B).

Grey seals have a more limited distribution than harbour seals. Approximately 40% of the world population breeds in European waters, mostly on remote islands around the coasts of the United Kingdom (Table 4·3). Grey seals produce their pups in autumn. The total number of pups born in colonies in the North Sea (particularly those at Orkney) has been increasing steadily for the last 20 years (Figure 4·13A). The total population of grey seals in the North Sea in 1991 was estimated at approximately 43 000. Radio-tracking has shown that adult grey seals regularly travel distances of 250 km between haul-out sites, and more than 50 km out to sea, apparently to feed. In the North Sea, the most prevalent food species of the grey seal are sandeels and larger gadoids, especially cod and, to a lesser extent, whiting.

Cetaceans

The harbour porpoise (*Phocoena phocoena*) is the most common cetacean species in coastal waters, particularly in the north and west. It feeds on a variety of fish and cephalopods. In some parts of the North Sea, there has been a decline in sightings in inshore waters. Population sizes and trends in the North Sea and the Kattegat/Skagerrak are largely unknown. However, analysis of sightings indicates that the harbour porpoise no longer frequently inhabits the Wadden Sea and the southern North Sea, but is still common in winter along the Danish, German, and northern Dutch North Sea coasts, in summer east of England, and throughout the year in the northern North Sea.

The white-beaked dolphin (*Lagenorhynchus albirostris*) is the most common cetacean species in the southern North Sea. It has been suggested that this species breeds off the Dutch coast in June and July, and migrates to waters of the United Kingdom to feed on herring and mackerel.

The bottlenose dolphin (*Tursiops truncatus*) has been recorded at low density throughout the North Sea. However, animals are observed year round at a number of sites, notably: the Moray Firth in Scotland; on the Cornish, Dorset, and Hampshire coasts of England; and at locations in Brittany and Normandy.

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*). Of the baleen whales, only the minke whale (*Balaenoptera acutorostrata*) is sighted regularly in the North Sea.

Strandings of marine mammals are systematically recorded in several countries bordering the North Sea. Sighting and stranding records are helping to elucidate the current state of populations in the North Sea and their distribution and migration patterns. However, investigations are still in such an early stage that definite statements cannot yet be made about any species. Several collaborative projects are under way to determine the causes of death of stranded cetaceans as well as to build up a comprehensive picture of the health and biology of cetaceans in the North Sea.

4.3. Interrelationships

Description of main communities

An essential aspect of protecting the living organisms and habitats of the North Sea is the identification of sites and species of importance for nature conservation. A structured approach is needed in order to describe the habitats and assemblages of species that are typical of any particular area. The concept of 'community' provides the basis for a structured description of marine sites and the changes they may undergo over time. The term 'community' applies to groups of animals and plants, particularly with respect to their biological relationship with a particular habitat. The habitat types in which specific communities develop may be separated according to their physical characteristics (such as substrate type, topography, and currents) and chemical characteristics (such as salinity, nutrients, and contaminants).

In general, the North Sea may be described as a region influenced by the land masses in its vicinity, with water depths of less than 200 m, in which there is interaction between the water column and the seabed. Coastal communities are complex but vulnerable as they are situated at the interface between terrestrial and marine ecosystems where human impact is the most intense. Humic substances and elements introduced with freshwater runoff from land are important for phytoplankton production. Their concentration is higher in shelf waters than in the open ocean. Organic detritus from the plankton in surface layers sinks to the sea bottom where it becomes the food of benthic bacteria and fauna and ultimately feeds demersal fish. The near-bottom water becomes enriched with mineralized compounds as a result of these processes, and in winter, when water stratification does not persist, it is recycled to the surface. In the zone from high-tide level to about 30 m water depth, the water column remains fully mixed all year round, and live plankton is transported continuously by turbulence from the surface layers to the bottom and back, coming within reach of the benthos. A wide variety of different benthic communities exists in this zone. Well-lit rocky bottoms are often covered by macroalgae, while poorly lit regions are dominated by sessile macrofauna. Owing to improvements in scuba-diving equipment over the last decade, greater knowledge has

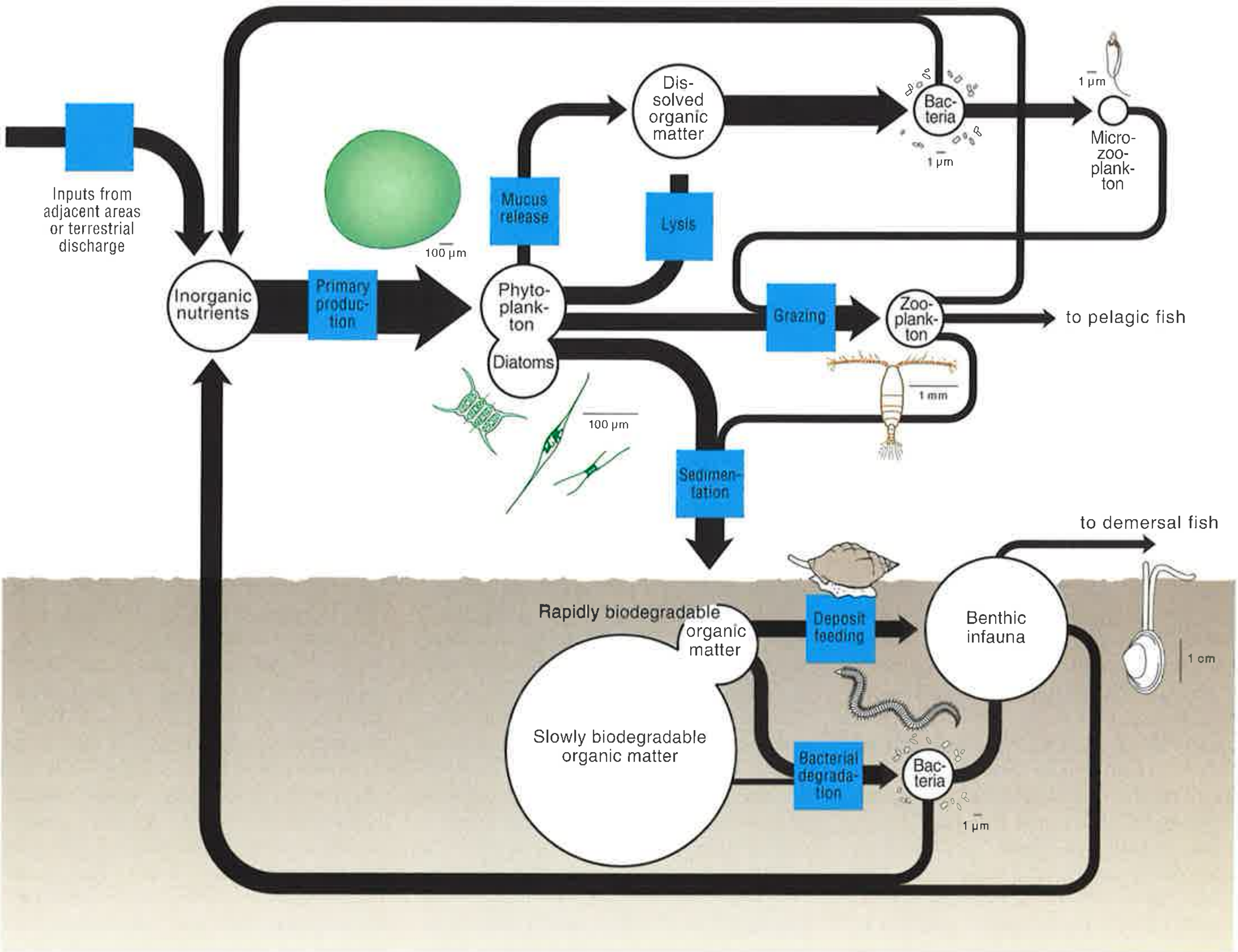

Figure 4·14. Major fluxes of nutrients through the lower trophic levels of a coastal ecosystem. Source: Fransz *et al.* (1991).
This simplified diagram of part of the food web gives an indication of the appearance and relative sizes of typical organisms (see scale bars), the biomasses of the components (size of circles), the pathways for transfer of nutrients between them, and the rates at which these transfers take place (width of arrows).

been gained about sublittoral hard-substrate communities dominated by kelps and the associated red algae. Gravel and sandy bottom communities occur wherever strong tidal currents prevail.

The boundary between terrestrial and marine ecosystems is inhabited by communities that are influenced by the sea only when very high tides or high onshore winds occur. Intertidal rocky-shore communities include a restricted variety of species, except on the lower shore, and show a marked zonation in relation to the degree of tidal immersion. Muddy and sandy intertidal sediments contain a variety of specialized organisms. Such communities develop extensively in the Wadden Sea, the Wash, and the Baie du Mont-Saint-Michel. These sites are of prime importance for wading birds, ducks, and other coastal species. Estuarine sites also provide shelter and food for spawning fish. Salt marshes are found in the upper reaches of sheltered intertidal areas. They display rich and often unique populations of marine plants and animals.

The various benthic communities have an important position in the food web which leads to exploitable production. Resting stages of many phytoplanktonic and zooplanktonic organisms overwinter on the seabed and repopulate the surface layers in the spring and summer. The processes of benthic–pelagic coupling are specific to the shelf sea environment and work together to make the North Sea very productive.

The North Sea as defined by the North Sea Task Force includes a small area of 'Oceanic Province' in the northwest, where waters are deeper than 1000 m. Organic detritus produced by phytoplankton and zooplankton in the surface layers of the oceanic province may be broken down in the water column, but otherwise sinks to the deep-sea bottom where mineralization by deep-sea bacteria and deep-sea fauna takes place. The resultant carbon dioxide, nutrients, and trace elements are then transported throughout the ocean in the deep-water circulation, and there is no direct recycling back to the surface of the North Sea.

Food chains/webs

The production of organic compounds from inorganic sea-water constituents is brought about by the photosynthetic activity of marine plants using energy derived from sunlight. These organic compounds are usually incorporated as plant tissue, which is of major importance as the primary source of food for animals. Most of the primary production in the North Sea is carried out by phytoplankton, although large marine algae growing in shallow water also play a part. Food-web pathways in a generalized North Sea coastal ecosystem are shown in Figure 4·14. It should be noted, however, that the flow of energy to the highest trophic levels can be more or less efficient within the food chains depending largely on the composition of the plankton community present.

In the deeper offshore areas of the North Sea, macroalgae become less important, and here it is almost exclusively phytoplankton photosynthesis that fuels the food chain. In general, phytoplankton production is not as high in the open North Sea as in the coastal zone. There are, however, a number of recent reports that suggest that the Dogger Bank area and its surroundings may exhibit higher primary production and more efficient energy transfer within the food chain than other regions of the open North Sea (Heip *et al.*, 1992), possibly owing to the particular hydrographic features that are dominant in this area. The special circumstances around the Dogger Bank may influence local contaminant distributions. Transfer of energy within the water column takes place through consumption of phytoplankton by zooplankton and, in turn, planktivorous fish by carnivorous fish. In addition, bacteria that are dependent on organic matter are consumed by small flagellates, which are eaten by microzooplankton, which are then eaten by larger zooplankton. Defecation and death at all stages in the planktonic food web supply organic detritus to bottom feeders. This organic matter is utilized by bacteria, microfauna, meiofauna, and then macrofauna. Deposit feeders in turn are consumed by predatory worms in the sediment and by predators/scavengers amongst bottom-feeding fish and by mobile epifaunal species, including crabs, bivalve molluscs, and starfish (Subregion 7b). Large stocks of pelagic copepods develop only in the northern North Sea, where they consume the summer production of phytoplankton; this may explain the low biomass of infauna in the northern North Sea.

The most prominent feature of the energy pathway in coastal waters is the close coupling of benthic and pelagic systems, and yet in the past these two systems have largely been studied separately. The general pathway in benthic systems, derived from case studies in the Channel, underlines the importance of allochthonous (originating from land or other sources) organic matter as a food supply to the benthos. A large proportion of the energy input is consumed by the bacteria which itself constitutes an important food source for meiofauna. The total demand of benthic consumers is significantly lower than the supply of energy. Even if a part of this surplus (the fraction of input energy not used by the food web) is buried, the major fraction may be exported to adjacent sea areas. Pelagic food-web dynamics in coastal areas indicate the role of the microbial grazers (protozoans, microzooplankton, bacteria) as the major link between planktonic primary production and mesozooplankton. Studies in the well-mixed waters of the western Channel suggest that regenerated production accounts for about 70% of annual production. This proportion is much higher than that in several other coastal ecosystems and may be an indicator of the importance of the microbial loop in Subregion 9.

Identical paths of energy transfer are present in the intertidal and shallow ecosystems. In the benthic food web, energy is transferred along the following pathway: microphytobenthos – bacteria – meiobenthos – macrozoobenthos – flatfish/birds – harbour seal. In the pelagic food web the pathway comprises phytoplankton – zooplankton – pelagic fish – fish-eating birds. In both the pelagic and benthic systems a microbial web is present in which organic matter is mineralized or transformed from organic matter into particulate organic matter by bacteria. It appears that the role of the so-called microbial food web is much more important than was assumed earlier (Billen *et al.*, 1990). Energy flow through the ecosystems of the Wadden Sea is highly dependent on the characteristics of the different parts of the sea that can be distinguished geomorphologically (intertidal:subtidal ratio) or hydrographically (degree of exchange with the North Sea; amount of input of fresh water and nutrients). In such coastal areas and estuaries, shrimps are of major importance as food for fishes, especially gadoids and flatfish. Conversely, adult shrimps and crabs are important predators of recently settled flatfish (1 to 2 cm). Shrimps are therefore keystone species in inshore and estuarine food webs. Suspension-feeding bivalves can very effectively crop phytoplankton from the water column (equivalent to the entire volume of a large marine bay being pumped over the gills of its cockle and mussel population every three or four days). They adapt quickly to increased nutrient loads and are thus a buffer against eutrophication. Many of the important shellfish species are exploited by near-shore fisheries that, especially in bivalve fisheries, may compete with predators such as eider ducks, common scoters, and oystercatchers.

The great significance of euphausiids makes the food web in the Norwegian Trench different from those of the shallow North Sea plateau. Euphausiids and caridean shrimps are prominent food sources of the gadoids. Only cod and haddock depend strongly on shrimps and other epibenthic crustacea and other benthos. Hence the most abundant fish species are primarily supported by a predominantly pelagic food chain where energy and matter flow from phytoplankton through euphausiids to fish.

Production

The minimum light intensity for photosynthesis is about 1% of the irradiation at the sea surface. Such intensity occurs down to 30 m water depth in the clear waters of the central North Sea, but no deeper than 10–15 m in the less transparent coastal waters of the southern North Sea. As most of the North Sea benthos lies deeper, phytobenthos (macroalgae, sea grasses, and microphytobenthos) contributes only little to the primary production of the North Sea.

Primary production in the sea is mainly carried out by photosynthetic phytoplankton. Estimates of the production at all levels of the marine food chain are imprecise because of difficulties with methods and definitions, and because of variability between areas and seasons. There have been no surveys to estimate primary production for the whole North Sea over an annual cycle, although the area south of 55°30'N was covered recently. The average annual primary production of the North Sea is probably in the range 150–250 g C/m^2 per year. In coastal areas the annual production can reach values of 400 g C/m^2 per year (Cadée, 1992). However, the phytoplankton biomass and production off the north-east coast of England are clearly much less than in central regions of the North Sea, but the reasons are not known.

The average annual production of copepods in the North Sea is 5–20 g C/m^2 per year, macrobenthos production is about 2.4 g C/m^2 per year, and fish production about 1.8 g C/m^2 per year. Direct production measurements of North Sea meiofauna do not exist, but indirect information based on respiration, body weight, and life history can be used to estimate an energy consumption of about 10 g C/m^2 per year. Benthic mineralization is important compared with mineralization in the pelagic compartment. Recent measurements show that benthic bacterial production in the surface layer of North Sea sediments is at about the same level as benthic community respiration. Therefore bacterial carbon demand must exceed total carbon input into the sediment, and internal recycling is essential. The contribution of meio- and macrofauna respiration to community carbon mineralization is probably relatively small, although macrofaunal bioturbation enhances bacterial production.

Of the total fish production, roughly one third is consumed by fish, one third is lost to other predators, disease, etc., and the remaining third is caught by fisheries (Daan *et al.*, 1990). Recent average annual landings of fish from the North Sea, Skagerrak, Kattegat, and Channel have been just over three million tonnes, plus a quarter of a million tonnes of invertebrates. This may be compared with average fish landings for the whole Northeast Atlantic of 9.4 million tonnes plus invertebrate landings of half a million tonnes. The total landings per unit area are among the highest for North Atlantic shelf areas.

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CHAPTER

5

Man's impact on ecosystems

5.1. Introduction

This section of the 1993 *QSR* draws attention to the effects of human activity on the North Sea marine ecosystem.

Ideally, it should be possible to relate inputs of substances, and their sources, to concentrations found in the environment. It should also be possible to indicate whether the concentrations found are likely to have adverse effects, either on the organisms directly exposed or on their predators, including man. Because of gaps in our understanding, some of which are explained in Chapters 2 and 3, only a few situations are amenable to such interpretation. Generally, although progress is being made towards the development of agreed assessment criteria, they are still very limited in number. It is important to focus attention on those areas where the exposure risks are highest, since it is here that problems are most likely to occur. In addition to the mobilization of contaminants, anthropogenic activities have many other sorts of impact on the environment. Among the more notable are those brought about through fishing, but changes in the environment caused by exploitation of mineral resources (including oil), construction of buildings, expansion of tourism, and other human intervention are also important.

The following text draws attention to these issues and expands on the degree of present understanding of their seriousness.

5.2. Nutrients and eutrophication

General aspects

The term 'eutrophication' has its origin in freshwater studies where it has a clear meaning and definition. The term has been adopted for reference to the marine environment as well, but it is often used with different meanings. In the 1987 *QSR*, eutrophication was defined as 'the process of enrichment of sea water with nutrients, especially of nitrogen and phosphorus, leading to increased production of phytoplankton'; such processes can stem either from natural phenomena such as upwelling, or from inputs of nutrients originating with human activity in the bordering land and coastal areas. The term is often used in a more restricted way to mean anthropogenic nutrient enrichment and is used in this sense in this report unless otherwise stated.

The build-up of nutrients (nitrogen and phosphorus) in the water along the coastal belt from the Netherlands to north of Denmark and in the Skagerrak and Kattegat was among the issues of concern identified in the 1987 *QSR*. This build-up was caused by inputs of waste water and inputs stemming from agricultural activities, in combination with the specific hydrographic conditions in these areas.

The 1987 *QSR* also noted that there had been marked changes in plankton populations in the North Sea in recent years and an increase in the level of production in some coastal areas of the eastern North Sea and the Kattegat. Although the exact cause could not be established with certainty, some changes appeared to be linked to nutrient inputs, particularly along the eastern coastal zone. In the German Bight off Helgoland, plankton biomass increased fourfold between 1962 and 1985, which correlated well with known increases in nutrient inputs. The increased occurrence of extensive plankton blooms often leads to severe damage to marine communities. However, the 1987 *QSR* stressed that the relationship between nutrient concentrations and levels of phytoplankton is not a straightforward one and that other factors, such as changes in meteorological and hydrographic conditions, may also play important roles.

Box 5·1. While the term 'nutrients' is generally understood to mean dissolved inorganic phosphorus and nitrogen compounds, dissolved organic phosphorus and nitrogen compounds are also present in sea water and, at times of inorganic nutrient depletion, the concentrations of these organic compounds will be considerably higher than those of inorganic nutrients. Data from the south-eastern North Sea (German Bight and Jutland coastal current) (Hickel *et al.*, 1989) confirm the presence of high percentages of organic phosphorus and nitrogen in coastal waters, with concentrations of 20 to 30 µmol/l. In spring, about 30 to 40% of total nitrogen consisted of dissolved organic nitrogen, and this percentage increased towards the north and after phytoplankton (e.g., *Phaeocystis*) blooms. In late summer and autumn, more than 70% of the total nitrogen was in the form of dissolved organic nitrogen. Only in the plume of the Elbe River was less than 30% recorded. Dissolved organic phosphorus was already elevated in spring phytoplankton bloom areas and increased in summer to 75% of the total phosphorus, with lower percentages (<30% in near-shore water). In general, phytoplankton are most efficient at utilizing inorganic nutrient forms.

Concern about the effects of an increase in the net nutrient (Box 5·1) influx into the North Sea from anthropogenic sources has led to a search for a trend in nutrient concentrations in the water column in order to quantify the effect. The search for nutrient trends in the North Sea has focused on winter data as a means of avoiding the effects of biological production that occur in other seasons. However, it is this biological production that leads to the concern about the nutrient flux.

When looking for changes in the North Sea resulting from reduced nutrient fluxes (owing to the implementation of control measures), parameters based on planktonic populations may well show the effects sooner (or more clearly) than chemical concentrations of the nutrients themselves. Certainly both biological and chemical parameters should be monitored.

Nutrient inputs and concentrations

Historical data on nutrient levels in rivers and coastal waters are limited in both amount and quality. This makes it difficult to draw firm conclusions regarding background levels in watersheds and coastal regions. However, considerable quantities of the nutrients in the freshwater run-off to the North Sea result from human activity, including urbanization, industrialization, and agricultural development. It is therefore also likely that the elevated nutrient levels in the coastal zone are largely caused by anthropogenic influences. The trends over recent decades for major sources of nutrient inputs (such as the rivers Rhine and Elbe) demonstrate that present-day conditions with very high nitrate and phosphate concentrations are due to human activities, mainly through intensified agricultural practices in the watersheds (Gerlach, 1990).

Recent data on nutrient inputs are given in Section 3.3. Summed data on riverine and direct discharges of nitrogen and phosphorus are given for North Sea coastal areas in Table 5·1. Ninety per cent or more of the freshwater-borne nutrients are discharged from a few main rivers, of which more than half is from the Rhine. The total input of nitrogen by rivers and direct discharges was about 0.9 million tonnes in 1990. Of this amount 75% of the input reached the coastal zone of the southern North Sea (Subregions 3b, 4, and 5; and Subregion 10, the Wadden Sea) (Box 5·2). The natural ecological balance may be further disturbed by the fact that silicate inputs and concentrations have remained relatively constant (see p. 56, 'Nutrient concentrations').

The second pathway of eutrophication, by airborne nitrogen loads, with a substantial part from motor vehicle traffic, is very important and can be of the same order of magnitude as the riverine sources in summer. Only recently have more detailed figures for airborne inorganic nitrogen compounds become available. Airborne contaminant inputs to the northern North Sea are only 50% of those to the southern North Sea. Total atmospheric nitrogen input for the North Sea is estimated to range from about 300 000 to 600 000 tonnes per year, varying according to the method used. In the central North Sea aerial transport is more important than fluvial transport. Measurements show that atmospheric inputs of ammonia and nitrogen oxides are higher than previously estimated.

In recent years great effort has been expended on estimating the input of nutrients to the North Sea from littoral countries. These calculations have revealed considerable interannual variability related to differences in riverine discharges. For phosphorus, there has been a declining trend in inputs. The nutrient inputs to Subregion 4 were at their height in the late 1970s and early 1980s, four and seven times greater than the inputs during the 1930s and 1940s for total nitrogen and total phosphorus, respectively. Since then, especially after 1985, the phosphorus input from the Rhine, which is responsible for approximately 75% of the riverine inputs to Subregion 4, has decreased markedly; the decrease from 1985 to 1990 was 30–40%. The decrease in the nitrogen input from the Rhine was less pronounced and of doubtful significance (van Bennekom and Wetsteijn, 1990; Körner and Weichart, 1992). From 1988 to 1991, nitrogen and phosphorus inputs from the Elbe decreased considerably, probably owing to low river flows during the period.

Nitrogen/phosphorus ratios determined from input data are much higher than the ratio of 16:1 which is characteristic of sea water. They are even higher in mixing zones such as estuaries and the Wadden Sea. Nitrogen/phosphorus ratios of 200:1 have been observed in the freshwater/saltwater interface at the head of estuaries in the Wadden Sea. The mean ratios for the discharges into Subregions 4 and 5 were 32:1 and 40:1, respectively, based on data for 1990. Ratios higher than 60:1 were calculated for the discharges into Subregions 8 and 6 in the Skagerrak and Kattegat and off the west coast of Norway. A surplus of about 300 000 tonnes of nitrogen would remain of the total input when phosphorus is used up with a normal nitrogen/phosphorus consumption ratio of 16:1 by phytoplankton in spring. This surplus nitrogen is reflected in high nitrogen/phosphorus ratios in coastal waters in winter and spring. The consumption of the surplus nitrogen occurs under conditions of phosphorus limitation once phosphate has been depleted. This is a significant change in the ecological characteristics of the coastal water masses of the North Sea, from a more balanced situation presumably on the side of nitrogen limitation to the present situation of marked phosphorus limitation due to the excess nitrogen in spring and early summer.

The surplus nitrogen is to a large extent in the form of nitrate. While there has been a reduction in inputs of ammonium and particulate nitrogen in direct and riverine discharges, there has been an increased input of nitrate to the southern North Sea. Large amounts of nitrate have been found in Subregion 8 in late spring. It is estimated

Box 5·2. *Scaling of nutrient inputs*

The nutrient inputs to coastal zones of the North Sea can be scaled to illustrate the relative magnitude of the inputs. This has been done for the direct and riverine inputs to coastal subregions. The input to Subregion 10 (the Wadden Sea) has not been treated separately but is included in the calculations of scaled inputs to Subregions 4 and 5. The scaling has been done in two ways: 1) the total annual input of nitrogen was divided by the volume of sea water in each subregion; 2) the annual nitrogen input was also expressed as an input per unit time and divided by the mean flow of sea water per unit time through each subregion. The latter case is more representative of the impact on the environment. In both cases the scaled nitrogen input is expressed as amount per volume (µmol/l), which is equivalent to the unit of nitrogen concentration in sea water. For reference, the background winter concentration of nitrogen as nitrate is 12 µmol/l in Atlantic sea water.

The scaled nitrogen inputs per volume are highest for Subregions 4 and 5 and the Kattegat part of Subregion 8. The same areas also show the highest inputs when scaled to flow. The scaled inputs are much lower for Subregion 6 and the Skagerrak part of Subregion 8.

Table 5.1. Summary of nitrogen (N) and phosphorus (P) inputs (10^3 t/year) to the North Sea in 1990.

	Nitrate (NO_3-N)	Phosphate (PO_4-P)	Total N	Total P
Belgium	19.5	1.25	30	2.0
Denmark (west coast)	21	0.2	25	1.0
Denmark (Kattegat)	31	1.0	35	1.5
Germany	140	4.0	190	11
Netherlands	210	11	350	24
Norway (west coast)	11	0	30	1.0
Skagerrak (Denmark, Norway, Sweden)	20.8	0.2	45.6	1.3
Sweden (Kattegat)	21	0	35	1.0
United Kingdom (east coast, north of Flamborough)	30	4	85	>3.0
United Kingdom (east coast, south of Flamborough)	61	14	80	n.i.
Total	565.3	35.7	905.6	45.8
Channel*	364	79	1411	193
Atlantic	7000	1000	n.i.	n.i.
Atmospheric	300–600	n.i.	n.i.	n.i.

* Sydow *et al.* (1990); n.i.: no information.

that the Jutland coastal current transports about 400 000 tonnes of nitrogen of anthropogenic origin each year. Much of this transport occurs in late winter and spring in the form of nitrate.

Eutrophication effects

'Eutrophication effects' are effects resulting from nutrient enrichment. Among these effects are increased levels of nutrients during periods when production is low, increased production and biomass of phytoplankton, changes in species composition including the occurrence of harmful algae, changes in benthic algae and animal communities, and changes in oxygen consumption in water and sediments. All of these events may occur entirely naturally, and eutrophication is considered as pollution only when such changes have deleterious effects.

When evaluating eutrophication effects, it should be remembered that:

1) reliable figures are rare because of the inherent difficulties of measuring anthropogenic eutrophication under conditions of high natural variability;
2) the few phytoplankton time series available for the North Sea are mostly land-based and thus monitor only near-shore waters, with the exception of the time series from Helgoland;
3) the high incidence of tidal mixing and storms in the North Sea makes it particularly difficult to delimit eutrophication effects;
4) given current limits of knowledge, it is impossible to predict the appearance of eutrophication effects and how harmful they may be.

Phytoplankton biomass and primary production

Nutrient enrichment can and does enhance primary production and phytoplankton biomass in some North Sea coastal waters and can change the order of succession and seasonal length of different phytoplankton groups by altering nutrient ratios. Elevated levels of nutrients are found off the continental coast, where the highest concentrations of chlorophyll-*a* and primary production in the North Sea are also found (Joint and Pomeroy, 1992). Annual primary production at monitoring stations in the Dutch coastal zone varies between stations and years, from less than 200 to 600 g C/m^2. There were no clear trends in nutrients or chlorophyll-*a* in these waters over the period 1976 to 1991.

In the Marsdiep entrance to the Wadden Sea a time series of phytoplankton data has shown an increase in the seasonal length of high cell concentrations of *Phaeocystis* spp. and higher chlorophyll-*a* levels since 1972, although the seasonal length of occurrence of *Phaeocystis* spp. was greater in the 1890s than in the early 1970s. At this site an annual production of 150 g C/m^2 was found during the 1960s and early 1970s, with a maximum of about 400 g C/m^2 in the mid-1980s and a subsequent decrease to the present level of about 250 g C/m^2. These changes are reflected in chlorophyll values and have been attributed to eutrophication.

At Helgoland nitrate has shown a continuing increase, especially after 1979, and phosphate increased until 1982. This increase in nutrient input has been paralleled by a general increase in phytoplankton biomass by a factor of 3 to 4 during the growing season (Radach *et al.*, 1990).

Data sets often show a relationship between nutrient inputs and river flow. Phosphate concentrations decline with increasing river flows owing to a dilution effect. Nitrogen salts are more soluble and are washed into rivers during floods, giving a higher volume transport of nitrogen to the sea. There are clear changes in the Helgoland time series for recent years which are attributable to variations in Elbe river flow. Interannual variations in chlorophyll-*a* concentrations off the Dutch coast and at the Marsdiep entrance to the Wadden Sea show good correlation with Rhine discharges (Cadée, 1992a,b). While these links with riverine sources of nutrients have been demonstrated, the nature of the response of phytoplankton to increasing anthropogenic sources of nutrients is not yet fully understood.

An analysis of Continuous Plankton Recorder (CPR) data from offshore waters in the southern North Sea for the period 1931–1990 has shown little evidence of a systematic change in large phytoplankton that can be attributed to nutrient enrichment. Observed trends in phytoplankton as well as zooplankton have been related to changing climate patterns (CPR Survey Team, 1992).

Phytoplankton species composition and harmful algal blooms

There is evidence of a shift in phytoplankton species composition. One of the best examples is the dominance of *Phaeocystis* spp. cell numbers and the duration of blooms, which clearly increased in the Marsdiep area (Cadée, 1992b). Earlier large blooms in the 1920s and 1930s in the Southern Bight cannot easily be compared with the present situation because of the lack of quantitative data from the coastal zone.

The Helgoland time series shows an increase in the ratio of flagellate/diatom biomass in summer since the mid-1970s, which is partly due to a large increase in microflagellates. An increase in flagellates has also taken place in winter, closely related to the increase in winter nitrate concentrations in the outer German Bight at high salinity values. In Dutch coastal areas, changes from a dominance of diatoms to a dominance of flagellates during recent decades have coincided with increasing nutrient inputs and may also be associated with changes in nutrient ratios.

In the Skagerrak/Kattegat region, there has been an increase in reports of unusual plankton blooms. Blooms of *Gyrodinium aureolum*, *Prorocentrum minimum*, and *Lepidodinium viride* were recorded in the 1980s. The *Chrysochromulina polylepis* bloom in 1988 was the result of a combination of physical and chemical conditions, among which the high nitrogen concentrations and high nitrogen/phosphorus ratios were eutrophication effects. The toxicity of this bloom may have been related to phosphorus limitation.

There are no long-term time-series data available on phytoplankton species composition which can be used to document trends for any area of the North Sea. The many blooms of phytoplankton algae – including toxic species – reported for the North Sea cannot be attributed to eutrophication effects alone. Often they occur in association with hydrographic fronts. However, eutrophication effects on phytoplankton species composition – and therefore shifts in the food web – cannot be excluded either, especially since shifts in the nitrogen/phosphorus ratio are known to have such effects.

Zooplankton

Reports on zooplankton response to eutrophication in coastal waters are few. The population of the copepod *Temora* sp. increased in the Marsdiep area from four to eight times, compared with 1973; this was attributed to nutrient enrichment. In the German Bight, an increase in small copepods and the cladoceran *Evadne nordmanni* was observed in the period 1974–1985. A decline in zooplankton density from 1960 to 1981 and the subsequent recovery observed in long-term measurements off the English east coast and from Continuous Plankton Recorder data cannot be linked with eutrophication.

Phytobenthos

Microphytobenthos (bottom diatoms) are particularly affected by nutrient enrichment. Primary production of phytobenthos in the Dutch Wadden Sea increased dramatically, correlated with an increase in discharges of phosphorus and nitrogen from the river Rhine (Cadée, 1984).

Excessive growth of macrophytes has been reported from localized sites in United Kingdom estuaries, the Wadden Sea, Danish inlets and bays, and the Kattegat. Large mud-flat areas in the Wadden Sea are covered with algal mats in summer (mainly *Enteromorpha* spp. and *Ulva* spp.), which leads to oxygen depletion and benthos mortality beneath this algal cover. Some changes in the vegetation of salt marshes in the Dutch Wadden Sea, such as a decrease in species diversity and an increase in *Elymus pychanthus*, are partly attributed to nutrient enrichment. All these changes are evidence of eutrophication.

Agricultural inputs of nitrogen along the west coast of Brittany have subjected some very confined areas of bays and estuaries to increased growth of the macroalga *Ulva lactuca*. Roughly 50 000 tonnes of this alga are removed from the beaches each year.

A general shift from long-lived macrophytes (kelp, wrack, eel grass) to short-lived nuisance algal species has been found in various estuaries and bays and in the German and Danish Wadden Sea. The depth range of eel grass in some Danish inlets has been reduced, as has that of macroalgae in the outer Oslofjord and along the Swedish west coast of the Skagerrak. The occurrence of black areas in Wadden Sea mud flats, where the sediment is anoxic up to the surface, is a possible sign of eutrophication due to high organic matter input. Such areas have been reported since 1984 and have increased in frequency since 1987.

Zoobenthos

Increased rates of plankton sedimentation or amounts of macroalgal debris will increase the quantity of organic seston that will affect the nutrient supply to the benthos as well as the oxygen requirement of the sediment. The increase in average stocks of brown shrimp along the Dutch coast has been ascribed to such an increase in organic matter. Benthic diatoms, which have also increased, have led to increased food resources for some macrobenthic species. As a result, during the last two decades there has been a two- to threefold increase in the biomass of macrozoobenthos on intertidal flats of the western Dutch Wadden Sea (Beukema, 1991). This increase has been accompanied by a shift towards greater dominance of polychaete worms. During the same period the nutrient concentrations and phytoplankton biomass have roughly doubled.

Changes in zoobenthic biomass and community structure have been documented in the Kattegat, the eastern Skagerrak, the Wadden Sea, parts of the Southern Bight, and the German Bight. Comparisons of benthos sampled in 1984–1985 with samples taken in 1911–1914 showed increased biomass and changes in species composition that were indicative of general organic enrichment. Monitoring of benthos during the 1970s and 1980s showed similar changes indicative of increased eutrophication in the 1980s. During the late 1980s there were reductions in benthic fauna in the southeastern Kattegat due to low oxygen content (Rosenberg, 1992). Reductions in zoobenthic biomass also occurred (Baden *et al.*, 1990).

The macrozoobenthic biomass in the German Bight has also shown an overall increase as a result of eutrophication (Rachor, 1990). Small deposit-feeding opportunistic worms proliferated in the German Bight and off the Jutland coast in the years 1981–1983 after severe oxygen deficits. These species have taken over the niche previously occupied by more long-lived species such as bivalves (Hickel *et al.*, 1989). The zoobenthos communities of the Dogger Bank region have shown changes possibly indicative of eutrophication (Kröncke, 1992). South and east of the Dogger Bank, several species occur in very high densities, but north of the Dogger Bank only two species, the small polychaete *Myriochele oculata* and the brittle star *Amphiura filiformis*, exist in such high densities. The biomass of the dominant brittle star *A. filiformis* has increased over the past 30 years in the southern North Sea, possibly owing to eutrophication, but has remained low north of the Dogger Bank.

Oxygen deficiency

Oxygen deficiency is a result of oxygen consumption during the decomposition of organic matter. Such deficits can, however, only be expected in bottom waters with reduced vertical water exchange rates. Oxygen deficits are, therefore, typical of eutrophied sea areas with at least temporary density stratification of the water column which reduces vertical turbulent water (and oxygen) exchange. Such areas are found in some intertidal estuaries, stratified waters of the Oyster Ground and the German Bight and off the west coast of Denmark, in many Norwegian fjords and Danish bays, and in the southeastern Kattegat (Figure 5·1).

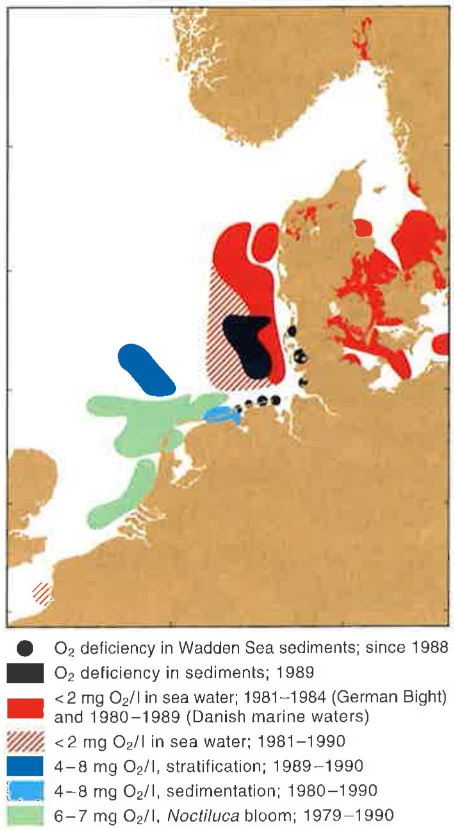

Figure 5·1. Oxygen deficiency in various zones of the North Sea. Source: OSPARCOM (1992).

Oxygen deficiency has been found in large areas in bottom waters of the southeastern North Sea, particularly during the summers of 1981–1983 (Westernhagen *et al.*, 1986). The observed deficiency in 1981 coincided with the occurrence of large phytoplankton blooms in the same area, an event which had not previously been observed. Trends of decreasing oxygen concentrations during the last decades have been documented for deep water in the Kattegat, basin water in Swedish and Norwegian fjords, and intermediate water in the outer Oslofjord (Andersson and Rydberg, 1988). It is likely that this trend is related to increased sedimentation and decomposition of organic material caused by eutrophication. A shift in this situation appeared to occur around 1980. Calculated rates of oxygen consumption in basin water in fjords along the

Norwegian Skagerrak coast have increased by about 50% since 1980. There is extensive exchange of water above the sill between the fjords and the coastal current. The increased vertical flux of carbon in the fjords may be due to an increase in the suspended organic matter in the water of the Norwegian Coastal Current.

5.3.

Chemical contaminants: levels of exposure and associated effects

Introduction

Since most contaminants enter the North Sea by outflows or run-off from the surrounding land, in particular via rivers, the highest concentrations are often found in estuaries and coastal areas, and thus the effects of contaminants on the ecosystem can be expected to be strongest here. This general picture can be influenced by additional inputs from sources at sea (ships, offshore platforms) and by inputs via the atmosphere.

After entering the sea, contaminants are usually diluted and widely dispersed. However, the adsorption of contaminants onto suspended particulate matter in the sea leads to elevated concentrations on the seabed in areas where this material settles, e.g., the Dogger Bank, the Oyster Ground, the Wadden Sea, the German Bight, the Skagerrak, and the Norwegian Trench. Elevated concentrations increase the likelihood that effects will be detected more frequently in such areas than elsewhere. Settlement areas that are also close to direct sources of input are doubly at risk.

Another important process is the bioconcentration, or bioaccumulation, of contaminants in the tissues of organisms. Bioconcentration is related to the biological availability of contaminants to organisms and to the metabolism and excretion of the contaminants or their metabolites. Therefore, similar levels of a specific contaminant can have different effects since it may be present in different forms with different availabilities for uptake. Bioconcentration presents a risk to consumers, including man.

The effects of contaminants on the ecosystem are very difficult to assess. Results of laboratory experiments give only limited information in relation to the field situation, on account of the complexity of the natural ecosystem and, in general, the co-occurrence of a multitude of contaminants in the field. Actual changes in the marine environment are often very difficult to discern owing to the high natural variability.

Concentrations of contaminants in biota are presented here using the original units, on the basis of either dry weight (d.w.) or wet weight (w.w.). An approximate conversion of concentrations in fish and shellfish from a dry weight basis to a wet weight basis can be achieved by division by a factor of 5. Conversion factors for other types of organisms are not known.

Effects of individual contaminants

Metals

In the following discussion of metals, concentrations in sea water refer to the dissolved phase.

The potential hazard of mercury, like other heavy metals, stems from both its direct effects and its bioaccumulation, which often lead to an increase in concentration up the food chain and with the age of the organism. Thus, high concentrations of mercury were observed in liver of seals from the English east coast and the Norwegian coast (up to 100 mg/kg wet weight) and in liver of harbour porpoises from the Belgian coast and the Kattegat (up to 500 mg/kg dry weight). The limited data also indicate that in birds (body tissue and eggs) rather high levels can be reached, e.g., 2.6–4.2 mg/kg d.w. in liver of common terns from the Western Scheldt Estuary, and around 0.6 and 2.3 mg/kg w.w. in eggs of oystercatchers and common terns from the German Wadden Sea (Becker, 1989). The ecotoxicological significance of these concentrations is not clear. The Paris Commission has concluded that the concentrations of mercury in fish flesh observed at present do not pose a risk to human health. The consumption of fish from the estuary of the Elbe has, however, been banned by German authorities because of high mercury content.

Lowest observed effect concentrations (LOECs) of cadmium are close to background concentrations in water of the North Sea (ca. 0.01 µg/l). Such concentrations occur in extensive areas of the coastal zones of the North Sea and in particular in some large estuaries such as those of the Tyne, the Humber, the Baie de Seine, the Western Scheldt, the Elbe, and the Sørfjord/Hardangerfjord and in the outflow of the Rhine/Meuse along the Dutch coast.

Bioaccumulation of cadmium in higher organisms occurs mainly in kidney and to a lesser extent in liver. The availability of data is very limited. For common terns from the Western Scheldt Estuary, high concentrations of 31 and 6.6 mg/kg d.w. in kidney and liver, respectively, have been reported. Seals along the east coast of the United Kingdom show mean concentrations around 0.25 (range < 0.04–1.0) mg/kg w.w. in liver. For kidney, only data from the Scottish coast are available, which show mean concentrations of around 1.2 (range < 0.04–4) and 1.6 (range 0.2–7.4) mg/kg w.w. for seals and harbour porpoises, respectively. The ecotoxicological significance of these concentrations is not clear. Tissue concentrations of 13–15 mg/kg w.w. have been considered hazardous.

Lead is strongly accumulated in shellfish, and can pose a risk to their predators, including man. Concentrations in mussels exceed the Benelux human consumption standard of 2 mg/kg w.w. (approximately 10 mg/kg d.w.) in some estuaries, i.e., those of the Tyne (4.6 mg/kg w.w.), and the Sørfjord/Hardangerfjord (up to 80 mg/kg); mussels from these areas are not used for human consumption. Lower, but still clearly elevated, concentrations in mussels also occur at other places along the English east coast. Although it is assumed that public health will be protected by the relevant regulations, it is not known what effects such levels may have on natural predators in the ecosystem.

The ionic component of total dissolved copper in sea water has been shown, through experimental studies, to have a deleterious effect on some phytoplankton and bacterial species at levels of 0.1–0.2 µg/l. High concentrations of total dissolved copper have been found in some contaminated estuaries such as the Tees (up to 10 µg/l), the Western Scheldt (up to 2 µg/l), and the Sørfjord, but also, decreasing towards the open sea, in the whole of the Southern Bight, the German Bight, and the Skagerrak/Kattegat. Although the actual concentrations of ionic copper in these areas are not known, they will be lower than the concentrations of total dissolved copper in sea water since part of the latter is associated with naturally occurring soluble organic carbon. This process effectively decreases the toxicity of copper with respect to phytoplankton. The decrease in toxicity is illustrated by the findings of one study of the Thames and Humber estu-

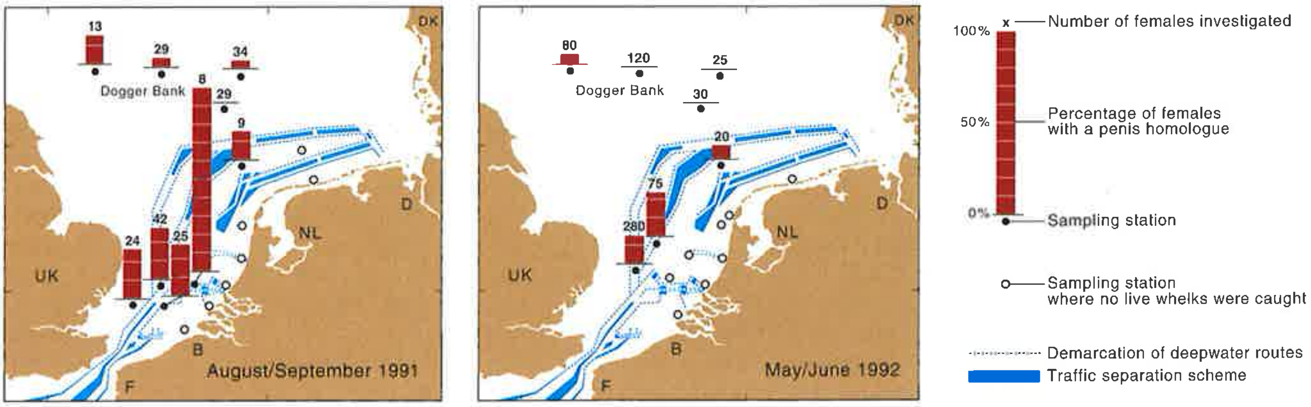

Figure 5·2. Relationship between catches of female whelks (*Buccinum undatum*), frequency of occurrence of penis homologues, and traffic separation systems in the southern North Sea. Source: Ten Hallers-Tjabbes *et al.* (1994).

aries, where total dissolved copper concentrations that exceeded the national quality standard of 5 µg/l for uncomplexed copper were found to be non-toxic to phytoplankton because the metal was bound to natural ligands. On the basis of the findings of one combined field and experimental investigation it was concluded that phytoplankton productivity could be affected in the coastal zones of the abovementioned areas, as could the species composition in the German Bight, which has shifted towards relatively resistant species such as the diatom *Thalassiosira punctigera*.

In order to make a proper assessment of the toxic effects of copper on phytoplankton in coastal areas, information from the following is required:

- measurements of the actual concentrations of ionic copper in these areas; and
- appropriate sublethal effects studies on phytoplankton in the laboratory and in the field.

Zinc is less toxic than the other heavy metals discussed above, and occurs naturally in higher concentrations. Here, too, there are no indications that the concentrations found in the open sea exert toxic effects in themselves. However, strongly elevated concentrations occur in the Tyne, Tees, Humber, Western Scheldt, and Sørfjord/Hardangerfjord estuaries, which exceed both the United Kingdom and the Dutch Environmental Quality Standards of 10 and 2 µg/l, respectively.

Apart from some slightly elevated levels in the estuaries of the Humber and Western Scheldt, nickel concentrations are generally close to background levels, and there are no indications that the concentrations found exert toxic effects in themselves, i.e., not considering their contribution to the total contaminant mix.

In conclusion, it appears that the greatest risks to the North Sea ecosystem from the metals studied stem from the effect of copper, mainly on lower trophic levels; from cadmium and mercury, on top predators; and from lead, on predators of shellfish. These effects are observed most frequently in estuaries and coastal areas, in part owing to the accumulation of metals in organisms.

Tributyl tin (TBT)

Exposure to tributyl tin, derived predominantly from anti-fouling paints, produces distinctive responses in various organisms, notably Pacific oysters (*Crassostrea gigas*) and dogwhelks (*Nucella lapillus*). Females of the latter species develop male sexual characteristics (termed 'imposex'), which in severe cases can lead to sterility and destructive effects on the population. These effects occur at very low levels of TBT, with no observed effect concentrations (NOECs) of 2 ng/l for dogwhelks and 20 ng/l for oysters. Contamination of North Sea coastal areas by TBT is widespread, arising principally from small boats and commercial vessels. In areas where statutory controls have been implemented, concentrations of TBT in water are generally falling and the rate of leaching of TBT from large vessels has been reduced by the use of copolymer rather than free-association paints.

Results from a Dutch survey in 1991/1992 indicate that TBT, probably from shipping, also affects the whelk (*Buccinum undatum*) population in the southern North Sea. The findings of the survey were that no whelks at all were present in the very busy coastal shipping areas, a high incidence of imposex in whelks was observed in the offshore deepwater shipping lane, and a low incidence was found on the stations near the Dogger Bank (Figure 5·2).

The results of a recent NSTF survey of the effects of TBT in the dogwhelk, carried out in coastal areas around the whole of the North Sea by the United Kingdom Department of the Environment, can be summarized by categorizing each of the sites studied (which included both areas close to harbours and open coasts) with reference to its potential for the maintenance of self-sustaining dogwhelk populations (Figure 5·3). It is clear from this study that most of the sites investigated in the North Sea showed significant levels of

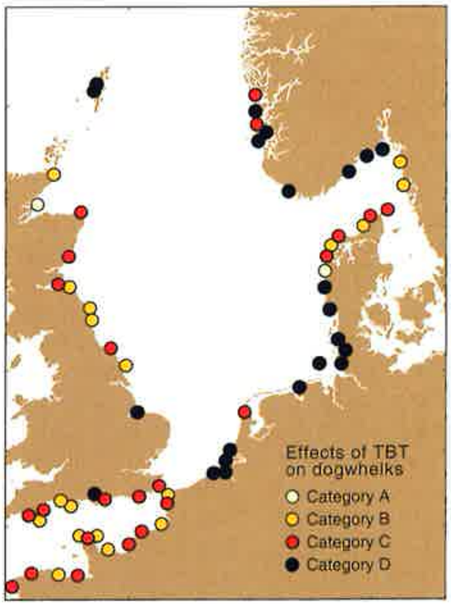

Figure 5·3. Effects of TBT on indigenous and transplanted dogwhelks (*Nucella lapillus*) in the North Sea. Source: Harding *et al.* (1992).
Category A: Dogwhelk populations showing little, if any, effect of exposure to TBT beyond that associated with areas distant from sources of TBT; Vas Deferens Sequence Index (VDSI) <2.
Category B: Dogwhelk populations showing some effects of exposure to TBT, but not to the extent that any significant effect on production of egg capsules would be expected; Vas Deferens Sequence Index (VDSI) 2–4.
Category C: Dogwhelk populations showing more marked effects of exposure to TBT, to the extent that reductions in the production of egg capsules would be expected; Vas Deferens Sequence Index (VDSI) 4–5.
Category D: Dogwhelk populations showing severe effects of exposure to TBT, to the extent that production of egg capsules would be prevented; Vas Deferens Sequence Index (VDSI) >5.

imposex in dogwhelks. The resultant reduction in the ability of the animals to reproduce is likely to have catastrophic effects on the populations of dogwhelks in the North Sea. Most sites fall into Category C (reduced production of egg capsules) or D (prevention of production of egg capsules). Historical records show that dogwhelks were formerly distributed much more widely in the North Sea than they are today.

TBT also affects other types of organisms, including phytoplankton and zooplankton (at levels > 1 ng/l), oysters (shell anomalies at > 2 ng/l, effects on reproduction at > 20 ng/l), and fish (reproduction 1–10 µg/l, behaviour 1–100 µg/l).

Oil

Man introduces large amounts of oil into the North Sea (see Table 3·19). This can affect the ecosystem in several ways, depending on the type of oil and how it occurs in the marine environment, e.g., attached to sedimenting particles, dissolved or dispersed in the water, or as slicks on the surface. Oil is an important source of polycyclic aromatic hydrocarbons (PAHs), the effects of which are discussed on the next page.

Oil in sediments

Accumulation of oil (measured as total hydrocarbons) in sediments occurs mainly from oil-contaminated drill cuttings discharged by the offshore industry, but depending on the water-current regime and depth it may also come from other sources (e.g., offshore production water). Typical concentrations in remote areas are normally in the range of 0.2–5 mg/kg dry sediment, although in some areas of the United Kingdom sector values in the range of 15 mg/kg dry sediment are found. Very close to platforms (within 50 m) oil concentrations as high as 10–100 g/kg dry sediment have been found.

The size of the area with elevated levels depends on several factors (e.g., the level of input, type of cutting discharged, bathymetry, and current regime). The estimated total area in the North Sea of contaminated seabed ranged from 1900 to 4500 km^2 in 1986. A recent estimate is ca. 8000 km^2. Although washing of drill cuttings leads in general to a reduction in the amount of oil discharged, there is as yet no indication that the scale of the affected area has been reduced.

Two types of adverse effects of discharges of cuttings can be distinguished: physical smothering and chronic pollution of the benthos. Of these, only the latter will be discussed here. Based on the relative abundance of sensitive species and the species diversity, the no observed effect concentration (NOEC) for macrobenthos is ca. 10 mg oil/kg dry weight of sediment (corresponding to approximately two to three times typical sediment concentrations). Above this level, a variety of effects become visible, such as reduction in number of sensitive species, increase in abundance of some opportunistic species, increased mortality, overall reduction in macrobenthos abundance, and reduced diversity of the whole macrobenthos community.

The adverse effects can be described as follows:

- concentrations > 100 mg/kg dry sediment: all types of effects occur from moderate to severe;
- concentrations < 100 and > 10 mg/kg dry sediment: at least some of the above (moderate) effects occur;
- concentrations > ca. 10 mg/kg dry sediment: sensitive species are absent or present in reduced densities, but opportunistic species increase in abundance (subtle effects).

After drilling has ceased, with time the oil in the sediment becomes less harmful. This may be attributable to changes in chemical composition and bioavailability of the oil due to weathering and/or adaptation phenomena in the benthic communities at those sites. No signs of macrobenthos recovery have been observed in highly contaminated zones six years after cessation of discharges of oil-contaminated drill cuttings, while in moderately affected zones recovery usually takes place within two to three years. The long-term and wider-scale effects are due to low biodegradation rates of some oil constituents and redistribution of contaminated sediments by tides and currents (Gray *et al.*, 1990).

Oil in water

Oil concentrations in sea water are generally low (about 0.2–3 µg/l). Elevated levels were found in the inner German Bight and, as a result of discharges of production water and cuttings and from flaring, around some northern offshore platforms. Reports from field studies on possible effects of elevated oil concentrations in water around platforms are very limited. However, experiments with caged mussels placed around drilling sites showed a reduced scope-for-growth (in some cases up to a distance of 5000 m), but no effects on the survival of the mussels. Mussels also showed reduced respiration rates when exposed to low oil concentrations. Furthermore, a lack of algal growth and a dramatic change in the metamorphosis of cod larvae were found at concentration levels lower than 50 µg oil/l. Plankton (particularly copepods), fish eggs, and herring larvae showed higher mortalities than controls when they were exposed to production water with oil concentrations as low as 5–15 µg oil/l, levels that are expected to occur within 500 to 1000 m downstream from a discharge site. Disturbance of physiological processes in the exposed organisms may well explain the toxicity of oil.

Tainting of fish has been observed at some sites where oil-based drilling muds have been used. Effects of water-based drilling muds on fish have not been observed. Laboratory experiments with sand gobies showed reduced swimming activity, followed by increased mortality when exposed to 0.3–1.2 µg/l of the water-soluble fraction of North Sea crude oil. However, no effect on herring was found.

Oil slicks

Birds are the main victim of oil slicks (Skov, 1991), but marine mammals can also be fouled. Oil slicks are frequently observed, originating from both ships and offshore installations, and are the result of illegal discharges or accidents. The majority of these slicks consist of ships' bilge oil, but crude oil and lubricating oils also occur as well as non-mineral oils. Other lipophilic substances can form sheets on the sea surface and have led to bird deaths. For instance, the death of over 10 000 seabirds off the north coast of the Dutch Wadden Sea islands has been attributed to illegal discharges of alkylphenols. High boiling alcohols and thiophenes have also been implicated.

It is estimated that oil slicks are responsible for the deaths of tens of thousands of seabirds yearly, including guillemots, common scoters, kittiwakes, eiders, razorbills, and herring gulls. Oiling rates of beached birds appear to be a remarkably stable figure that is characteristic for species and regions and – most important – for the level of pollution at sea. In general, no clear trend in the oiling rate has been registered over the last 20 years, although in some local areas, such as the Shetland and Orkney isles and along the German coast, a decline has been observed.

Polycyclic aromatic hydrocarbons (PAHs)

Although PAHs are compounds that occur naturally, concentrations in the North Sea environment are enhanced by inputs from human activities, e.g., from discharges of oil (including oil-contaminated cuttings), incomplete combustion processes (including flaring), and industrial effluents. Information on the occurrence of these compounds in the North Sea is rather scarce and almost no information on inputs is available. PAHs appear to be widespread, particularly in sediments, including those in offshore areas such as the Dogger Bank and the Oyster Ground, while relatively high levels occur in the Skagerrak and the Norwegian Trench.

At the ICES/IOC Bremerhaven Workshop (Stebbing and Dethlefsen, 1992) biological effects of contaminants were measured along two gradients, from a drilling rig and in a transect from the German Bight to the Dogger Bank. At the rig site the bottom was overlaid with storm-transported sand; PAHs were found in one or two deep-burrowing invertebrates. In the German Bight transect a variety of effects were found in dab, including pre-neoplastic lesions and elevated EROD activity, and these effects correlated with the contamination gradient, which included PAHs but also PCBs and heavy metals.

Synthetic organic chemicals

Man introduces an enormous variety of synthetic organic chemicals into the North Sea, but knowledge of which compounds are occurring and at what concentrations – let alone their effects – is extremely scarce. This is illustrated by the often very low proportion of total extractable organochlorines and organobromines from sediments that have been positively identified. Many of the synthetic organic compounds appear to be degraded in the environment. Other compounds degrade only very slowly, if at all, and even when reductions in inputs take place, if the compounds have deleterious effects, improvements in the environment will only take place on very long time scales.

Many halogenated organic contaminants have been detected in estuaries and in the open North Sea, in particular in sediments and organisms. These include PCBs, the DDT group, hexachlorobenzene, octachlorostyrene, hexachlorocyclohexanes, polychlorinated terphenyls, polychlorinated dibenzodioxins, polychlorinated dibenzofurans, polybrominated diphenylethers, and polybrominated biphenyls.

Of these substances, the PCBs, which generally occur in the highest concentrations, have received much attention in recent decades. Yet there are only a few indications of decreasing trends, although knowledge of the toxic properties continues to increase. High concentrations have been observed particularly in predators such as mammals and birds. For PCBs in fish liver there is a clear decreasing gradient from south to north in the North Sea, although there are also locally high concentrations in fish in northern coastal regions. For mussels as well, higher concentrations of PCBs are generally found in the Channel and southern North Sea than in northern regions. High levels of PCBs have also been found in the liver of deepwater fish from the Norwegian Trench and Skagerrak.

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 CBs (>100 µg/kg fat weight), which exhibit a dioxin-like toxicity, have been detected in seals from the North Sea (Brouwer *et al.*, 1989; Hall *et al.*, 1992).

The ICES Advisory Committee on Marine Pollution (ICES, 1992) considered the following seal populations in the North Sea to be exposed to threats, as specified: harbour seals in the Wadden Sea (organochlorines); and grey seals in the southwestern United Kingdom and in France (organochlorines, fisheries interactions, and disease).

Organochlorine compounds, in particular dieldrin, DDTs, and to a lesser extent PCBs, in fish ovarian tissue have been shown in laboratory experiments to reduce the hatching success of North Sea whiting (Westernhagen *et al.*, 1989).

The fact that relatively high total DDT concentrations, particularly in biota, still occur, combined with the clear concentration gradients in several estuaries (e.g., Thames, Western Scheldt, Weser, Elbe, Göta River), calls for an investigation into the sources. The origin and toxicological significance of the relatively high levels of toxaphene observed in fish liver and marine mammal blubber should also be explored.

Chemicals used in mariculture

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 localized. Most of the antibiotics used are persistent in the environment, and spread from the farms to surrounding areas, where accumulation in sediments may occur. Residues of oxolinic acid have been found in wild fish, shellfish, and crustaceans in close proximity to fish farms, and the concentrations may far exceed levels accepted for human consumption (0.01 mg/kg in Norway). Little is known of the effects of these antibiotics, which can also reach wild fish and can induce the development of resistant bacteria (Björklund *et al.*, 1990).

Radionuclides

Both natural and artificial radionuclides are present in the North Sea ecosystem. The most important natural nuclide emitting radiation doses to biota or humans is the alpha emitter polonium-210. Enhanced levels are known to exist in areas influenced by waste discharges from the phosphate-ore processing industry. Elevated levels of polonium-210 are detected mainly in shrimps and mussels, but their impact on predators of these shellfish remains unknown.

An estimate of the maximum likely individual dose to man from natural radionuclides amounts to about 2 mSv per year, based on a conservatively high estimate of the consumption of marine products. Studies (e.g., Woodhead and Pentreath, 1989) have shown that dose rates to the marine organisms themselves would, at these levels, not be significant at individual or population levels. The same conclusion holds for artificial radionuclides: caesium-137 is the most important such nuclide discharged into the North Sea area, mainly from the reprocessing plants at Cap de la Hague and Sellafield, and the dose to man is at least two orders of magnitude less than the dose from natural radionuclides indicated above.

Combined effects of contaminants

Introduction

Measurements of marine pollution using biological indicators provide information on the bioavailability of contaminants and the integration of the effects of multiple exposures and exposure over time. Multiple exposure is understood to mean the combined action of all chemical contaminants. Even if these contaminants are present at concentrations too low to cause gross harmful effects, they can cause a suite of biochemical reactions in marine organisms generally called stress. Amongst the results of prolonged stress is the suppression of the immune system, thus increasing sensitivity towards the impact of infectious agents and parasites. Natural factors, such as temperature extremes and fluctuations of salinity, or anthropogenic activities, such as fisheries, can aggravate these reactions. Biological effects techniques measure the integrated response to all possible factors. In recent years, considerable research has been devoted to the development of such techniques, several of which were considered to be sufficiently well tested to be recommended for incorporation in the Monitoring Master Plan (MMP).

Results of three of the recommended techniques are discussed below:

- monitoring of fish diseases;
- monitoring of the induction in dab (*Limanda limanda*) of the mixed-function oxidase enzyme (ethoxyresorufin-O-deethylase, EROD);
- oyster embryo bioassays in sea water and in sediment elutriates (water extracts of sediments).

Results of a fourth technique that was recommended, monitoring of the macrofaunal community of benthos, are discussed under the section on effects of oil, because observed effects could specifically be linked to the offshore industry. Effects on the benthos of eutrophication, fishing activities, waste dumping, and sand and gravel extraction are discussed elsewhere.

It should be noted that none of the techniques selected directly treat the questions of either the acute or the sublethal toxicity of the contaminant load present in sediments. There is a real need for sensitive *in situ* bioassays to measure sediment toxicity using organisms that normally live in sediments. This need has yet to be seriously addressed.

Two workshops have been held to compare measurements of biological responses to contaminants along field gradients: the IOC Group of Experts on the Effects of Pollutants (GEEP) Workshop in Oslo in 1986, and the ICES/IOC Workshop on Biological Effects of Contaminants in the North Sea in Bremerhaven in 1990. These workshops concluded that in complex contaminant gradients, the use of single techniques provides only limited information, and an appropriate suite of biological effects techniques should be chosen, based upon the objectives of the monitoring programme and the nature and concentrations of the suspected contaminants.

Fish diseases

Studies of fish diseases in relation to pollution have been conducted for a number of years. Fish diseases are a result of a combination of causes. Due to this complexity it is usually difficult to explain the process of disease initiation and development. Many of the fish diseases currently under study are considered to be subject to spatial, temporal, and biological variations that have natural or as yet unknown origins. Thus, considerable differences in disease prevalence levels can occur with no known association with pollution, and a basic understanding of these variations is essential to evaluating the role of pollution in the aetiology of fish diseases.

Reports indicate that high prevalences of some fish diseases occur in known areas of pollution in the North Sea. High prevalences of epidermal hyperplasia/papilloma in dab have been found in the former dumping grounds for wastes from titanium dioxide production in the German Bight and off the Dutch coast as well as at the outflow of the rivers Rhine/Meuse, off the Humber Estuary, and on the Dogger Bank (Vethaak and van der Meer, 1991; Dethlefsen *et al.*, 1987).

Similarly, there is evidence of a correlation between the occurrence of liver tumours in North Sea flatfish and contaminants, particularly chlorinated hydrocarbons and PAHs. Higher-than-average prevalences of liver tumours have been found in dab in the German Bight, off the Dutch coast, on the Dogger Bank, and off the Humber Estuary, while pathological changes in liver have been found in flounder (*Platichthys flesus*) from the Elbe Estuary and off the Dutch coast (Peters *et al.*, 1987). In contrast, fish disease data from Scottish waters revealed no adverse effects of sewage sludge dumping.

The summary statement of the ICES/IOC Workshop on Biological Effects of Contaminants in the North Sea held in Bremerhaven concluded that the occurrence of liver tumours in some North Sea flatfish species could indicate exposure to carcinogenic compounds (Vethaak, 1992). However, further evidence is needed to establish a causal relationship as correlation does not necessarily indicate causation.

Apart from the influence of contaminants, it has been shown that under conditions of low dissolved oxygen concentrations, higher prevalences of lymphocystis and epidermal hyperplasia/papilloma in dab have occurred along the Danish west coast and in the Kattegat. Furthermore, fluctuating salinity conditions in the tidal areas of the Elbe, Weser, and Eider rivers as well as near the outlets of sluices in the Dutch Wadden Sea were found to be correlated with elevated prevalences of externally visible diseases of flounder.

Box 5·3. *EROD*

Enzymes are proteins in organisms, some of which are able to catalyse reactions that can lead to the detoxification of contaminants. This process may, however, also lead to the production of biochemically active intermediates that may have the potential for causing damage to biological molecules such as DNA. In some cases the enzyme is only produced in response to the presence of the substance in the cell, a process referred to as induction.

The mono-oxygenase family of microsomal enzymes, collectively termed the cytochrome-P450 complex, is present at high concentrations in the liver of fish and is responsible for the biotransformation of a variety of both endogenous compounds (e.g., steroid hormones) and exogenous compounds (environmental contaminants). The environmental induction of a specific P450 enzyme, measured as ethoxyresorufin-O-deethylase (EROD) activity, has been shown in response to compounds such as polycyclic aromatic hydrocarbons, planar polychlorinated biphenyls, dibenzo-*p*-furans, and dioxins.

Induction of EROD will result in either detoxification (deactivation) and enhanced excretion of the contaminant, or toxification (activation) and increased toxicity, mutagenicity, teratogenicity, and/or carcinogenicity of the contaminant or its intermediate forms.

Which of these processes occurs will depend on the chemical nature of the compound(s) causing induction as well as the ability of the organism to respond. However, induction of EROD activity is not a general index of environmental quality, and the consequence of EROD induction for the biological fitness of fish populations has not yet been established. This is clearly an area where further research is required. Nevertheless, induction of EROD activity constitutes evidence that a limited range of contaminants with specific structural characteristics (e.g., PAHs, planar PCBs, dibenzofurans, and dioxins) are present at levels that are capable of exerting biological effects.

Mono-oxygenase (EROD) activity

Data on measurements of mono-oxygenase activity, as shown by ethoxyresorufin-O-deethylase (EROD), in the liver of dab (*Limanda limanda*) (Box 5·3) were collected under the Monitoring Master Plan (MMP). The assessment of these data was, however, complicated by the fact that each laboratory had used its own method for EROD measurements, which led to problems with comparability of the results. Nonetheless, these MMP data showed elevated EROD activity at a number of locations:

1) at sites close to the mid-line of the North Sea, which may be associated

with activity of the oil and gas industry;
2) in the central North Sea in close proximity to the eastern edge of the Dogger Bank; and
3) in industrial estuaries and enclosed water bodies that show evidence of local contamination, e.g., Firth of Forth, Oslofjord, Glomma Estuary, and in the plumes of the major rivers entering the German Bight.

Oyster embryo bioassay

The oyster embryo bioassay (Box 5·4) was included in the MMP (but only the Netherlands and the United Kingdom provided data) and was also tested extensively during the ICES/IOC Workshop on the Biological Effects of Contaminants in the North Sea. None of these studies has detected a significant response in offshore sea-water samples. Responses of biological significance have only been detected in bulk samples of the sea surface microlayer (the microscopic surface layer of the sea in which, during calm weather, elevated levels of contaminants can be found) or in water samples obtained from heavily industrialized estuaries. The bioassay has been used to measure the toxicity of sediments by elutriating them with clean sea water and testing the extracts obtained. Again, the results show that sediments that can release toxic substances are present in some industrialized estuaries.

> Box 5·4. *Oyster embryo bioassay*
>
> The oyster embryo bioassay measures the development of the embryo of the oyster (*Crassostrea gigas*), from cleavage through to the stage when the paired hinged shells have developed (the so-called 'D'-shaped larvae), in relation to water quality. At a temperature of 24°C normal development takes approximately 24 hours, and the test is therefore comparatively short-term. The concept of the oyster embryo bioassay is attractive because it utilizes an organism going through a very intense period of metabolic activity, in which it is likely to respond to chemicals that are teratogenic as well as acutely toxic; the bioassay is also relatively simple to perform.

The results have demonstrated that:

- there are water quality problems in the heavily industrialized estuaries of the Tees and Tyne, but no apparent problems with water quality in the other United Kingdom estuaries sampled or in the open North Sea;
- some estuarine and shallow-water sediments contain relatively easily liberated toxic substances, particularly industrialized estuaries in the United Kingdom and the Netherlands.

Embryonic malformation rates

It is generally accepted that the early life stages of fish are the most vulnerable to pollution. Studies of the development of pelagic fish eggs in the North Sea showed a wide variation in embryonic malformation rates (10–50%). However, these rates were consistently higher than average (up to 80%) in the coastal waters of the southern North Sea (Cameron *et al.*, 1992).

Other effects of contaminants

Several other adverse biological effects attributed to pollution have been reported. These include:

- toxicity to *Thalassiosira pseudonana* in a phytoplankton bioassay of sediment elutriates from the Wear and Tees estuaries, which may be due to organic contaminants;
- mortality and reduced growth of fry of viviparous blenny in several estuaries (Svinesund, Idefjorden, Göta River, Stenungsund) along the Swedish Skagerrak coast (e.g., Jacobsson and Neuman, 1991);
- the occurrence of shell disease in brown shrimp in the Wadden Sea and the inner German Bight (Knust, 1987);
- inhibition of the reproduction of the starfish *Asterias rubens*, possibly as a result of high levels of cadmium and PCBs.

5.4

Impact of fishing activities

Introduction

The most obvious direct effect of fishing is the removal of fish and shellfish from the ecosystem. At present between 30 and 40% of the biomass of commercially exploited fish species in the North Sea is caught each year. The catches are taken by a variety of fishing gears. Figure 5·4 shows the percentage of the landings taken by major gear categories in 1989. Industrial fisheries using small-mesh trawls account for more than half of the total landings. Purse seines, which are used for pelagic species, and otter trawls, seines, and beam trawls, which are used in the fisheries for roundfish and flatfish, share most of the remainder. The development of the fisheries in the North Sea is summarized in Chapter 1. The impact of shellfish fisheries on the ecosystem is not covered in the present chapter. Extensive information can be found in the subregional assessment report for the Wadden Sea (Subregion 10).

In addition to the catch of target species, fishing involves by-catches of non-target fish and other organisms. The various methods of fishing differ in their impact by being more or less selective. Some fishing gear, such as beam trawls, cause mortality of benthos, while others, such as gillnets, incidentally entangle and kill seabirds and marine mammals. Unwanted by-catch and the offal resulting from gutting fish at sea are usually thrown overboard. This provides food for a number of scavenging species such as gulls and other species of seabirds often found around fishing vessels.

Fishing may change the physical environment. Some active gears, such as bottom and beam trawls, disturb the seabed, leading to resuspension of fine sediments and displacement of rocks and boulders. Fishing activities also generate litter, both in the form of lost gear and as debris comparable to that produced by shipping in general.

The direct effects of fishing in turn can lead to indirect effects such as the modification of predator–prey relationships, changing the flow of energy through parts of the ecosystem. They can also lead to the modification of

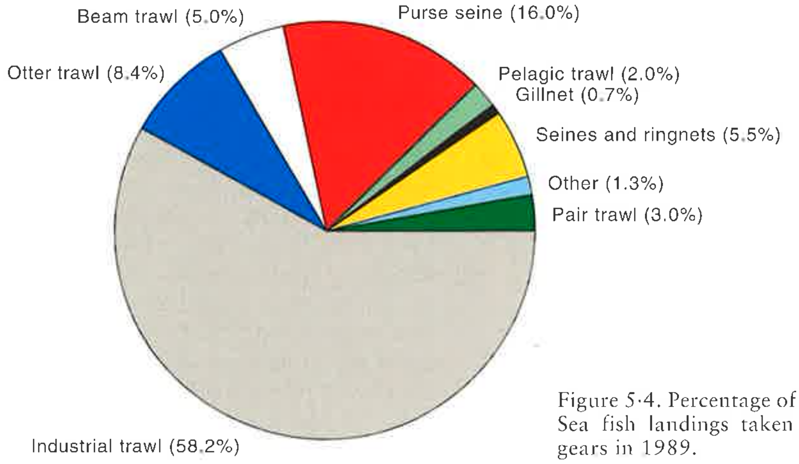

Figure 5·4. Percentage of total North Sea fish landings taken by various gears in 1989.

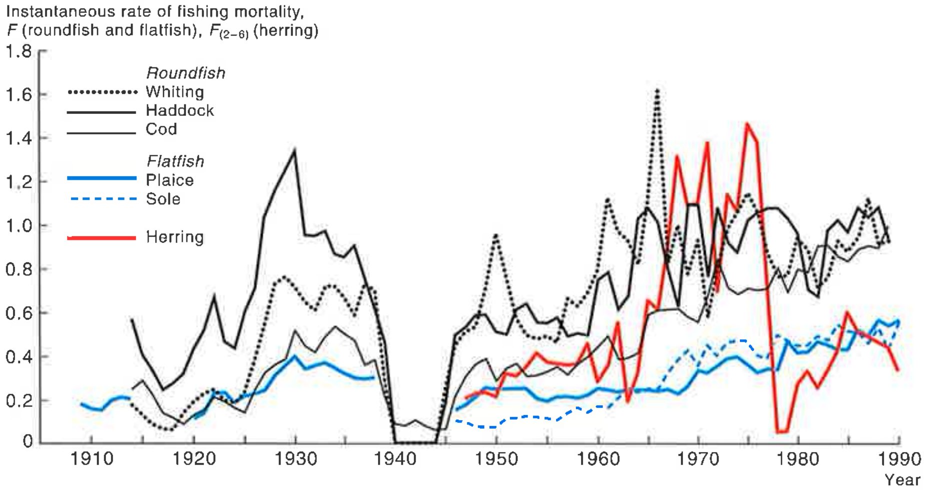

Figure 5·5. Intensity of fishing for North Sea roundfish, flatfish, and herring, expressed as the instantaneous rate of fishing mortality on fully exploited age groups (roundfish and flatfish) and the 2–6 year age group (herring). Source: ICES (1994). See Box 5·5 for further explanation.

habitats and possibly to evolutionary changes in the biology of affected species.

Fisheries exploit species against the background of a variable environment which is a major source of perturbation to the ecosystem. The changes wrought by fisheries should thus be viewed as one of several anthropogenic effects in a system that has no long-term equilibrium. Given the variability of the environment and the complexity of the interactions between the various components of the ecosystem, it is generally difficult to separate changes due to fishing from changes due to other factors. Furthermore, fishing has a long history in the North Sea, and any major changes attributable to fishing may have occurred decades ago. In many cases the present levels of perturbation constitute the normal condition for the duration of the data series available. For these reasons very few of the longer-term effects of fisheries have been documented.

In general the long-term effects of fishing on the marine biota are impossible to predict at the species level. While short-term effects may be predicted, the long-term consequences to species may be quite elusive. One important exception to the rule of limited predictability is the possible elimination of a vulnerable species by sustained overexploitation. Slow-growing species with low fecundity (e.g., rays) are the most likely candidates for such local extinction.

Development of North Sea fisheries and fish stocks

Significant technical developments in fishing had already taken place by the end of the nineteenth century, and the pace of innovation has accelerated since then. Many of the technical developments have led to more efficient exploitation of the various commercially important resources, but their effects on other parts of the ecosystem are less clear. Some developments may have reduced the effect of fishing on non-target species, such as, for example, the use of echo sounders and fishing charts to direct fishing more precisely onto the target species. Others, such as the twin beam trawl and some gillnets, may have increased the effect by augmenting by-catches of other species in the quest for higher fish catches. For these reasons the general effect of fishing on the marine environment cannot be related in any simple way to historic trends in the level of fishing effort.

The trend in the fishery for roundfish is reflected by the fishing mortality generated on cod, haddock, and whiting (Figure 5·5). Fishing mortality of haddock and whiting has been high and has fluctuated throughout most of this century. Fishing mortality of cod has generally been lower, but has increased markedly since 1960 to a level matching that of haddock and whiting. Haddock, and to a lesser extent whiting, are caught in the northern North Sea, while cod is caught throughout the sea. As a result of a number of strong year classes, catches of cod, haddock, whiting, and saithe (the major commercially important species of roundfish) increased dramatically in the 1960s. This increase, which is generally referred to as the 'gadoid outburst', has been followed by a gradual decline in landings since 1970.

The trends in fishing mortality of sole and plaice, the two major commercially important species of flatfish, are shown in Figure 5·5. For both species, fishing mortality has increased steeply in recent years, a development linked to the introduction of twin beam trawlers in the 1960s, and the use of heavier tickler chains in front of the net in order to disturb flatfish on the seabed. This fishery mainly takes place in the southern North Sea south of 55°N.

The intensity of fishing on North Sea fish stocks varies according to species. A number of stocks are or have been subject to 'overfishing' (see Box 5·5). In some of these cases the ICES Advisory Committee on Fishery Management (ACFM) considered that the stocks concerned were outside 'safe biological limits' in 1992 or were expected to become so at current levels of fishing. These stocks are: cod in the Kattegat; cod, haddock, and saithe in the North Sea; sole in the Channel; and North Sea mackerel (ICES, 1993). While fishing was undoubtedly an important factor in the decline in abundance of these stocks, poor recruitment is also a contributory factor. In another stock that was at its lowest recorded level in 1992 – the Shetland sandeel – the stock decreased as a result of natural factors (Box 5·6).

Box 5·5.

Overfishing

The term 'overfishing' is used in two different ways. 'Growth overfishing' occurs when fishing activity is so heavy, or when the fish taken are so small, that the fish are not able to achieve their full growth potential before they are caught. The result of this type of overfishing is economic inefficiency. Intensive fishing can also progressively reduce the stock until it no longer produces enough eggs to regenerate itself each year. This is called 'recruitment overfishing' since it affects the recruitment of new fish to the population. Given the inherent variability in the survival of small fish before they 'recruit' to the fishable stocks, this type of overfishing is very difficult to diagnose. From a conservation point of view, however, it is more serious because, if not corrected, it may result in stock collapse.

Fishing mortality and fishing effort

Several tables and figures in this report refer to 'fishing mortality', which is a measure of the proportion of the stock in the sea that is taken by fishing. Fish also die as a result of natural mortality (predation, disease, etc.), the rate of which differs between species and changes with the age of the fish. Fishing mortality can be expressed as a percentage or as a 'fishing mortality rate', an expression of the likelihood that a fish will die at any instant in time. Mortality rates due to different causes are thus additive, whereas percentages are not. As a result, it is not possible to provide a simple conversion between the two; however, a fishing mortality rate of 1.0 is approximately equivalent to a fishing mortality of 60–70% over the course of a year.

An additional advantage of using 'fishing mortality rates' rather than percentages is that they are to a first approximation proportional to the amount of fishing effort. 'Fishing effort' is a measure of the amount of fishing, that is, a combination of the number of vessels, the size and power of the vessels, the time spent fishing, and the effectiveness of the vessels at catching the fish in question (which is related to technological development). Because of the close relationship between fishing mortality and fishing effort, a series of 'fishing mortality rates', or 'fishing mortalities' for short, can be a useful surrogate for 'fishing effort'.

Box 5·6. *Interaction between sandeels and seabirds: a case history at Shetland*

Several species of seabird at Shetland have shown reduced breeding success in the past few years, and in the case of the Arctic tern (*Sterna paradisaea*), almost no young were produced in the period 1984–1990. During the breeding season, the surface-feeding and smaller pursuit-diving species feed their young predominantly on 0-group sandeels (*Ammodytes marinus*), although the diet of some seabird species has recently switched to other species. Seabird studies indicate that breeding failed as a result of inadequate feeding of chicks by the parents.

The variation in 0-group sandeel abundance between 1990 and 1992, following the closure of the fishery, was similar to that seen whilst the fishery was in operation. This variation could not be explained by changes in the spawning stock biomass on Shetland grounds. Rather, there was evidence that changes in early survivorship and immigration were involved, since larval growth differed markedly between good and poor year classes and high recruitment coincided with the appearance of high offshore densities of sandeels. It is postulated that the change in sandeel densities offshore was related to changes in the survival and dispersal of larvae from a large spawning area near Orkney, but the only relevant evidence is indirect.

The findings thus indicate that the seabird breeding failures were not directly caused by the sandeel fishery but by natural factors affecting the early life history of sandeels. Such events have been widely reported in seabird populations elsewhere and demonstrate the dependence of breeding seabirds on fish recruitment. The relative effect of the fisheries and environmental factors in most of these cases is not certain, but there is general agreement that both factors may play a part.

The fisheries for herring and mackerel, the two major commercially important pelagic species, have shown some significant changes. Figure 5·5 shows the time series of fishing mortality on herring, which extends back to 1947. Fishing intensity increased slowly through the 1950s and 1960s as the trawl fishery for herring increased, and then trebled abruptly owing to the rapid expansion of the purse-seine fishery. The purse-seine fleet initially depleted the North Sea mackerel stock, and despite a great reduction in fishing mortality from 1970 onwards the stock has not yet recovered. For herring the fishing mortality remained at an elevated level until the stock collapsed in the second half of the 1970s, after which the herring fishery was greatly reduced. Owing to strong recruitment the herring stock recovered in the 1980s, and fishing mortality has since returned to values comparable to those of the earlier part of the time series.

Prior to the 1970s herring and mackerel were the main species used for production of fish meal and oil, but then sandeel, Norway pout, and sprat increased in importance. Norway pout and sprat were mainly important in the 1970s, after which the catches of these two species declined. From 1985 onwards sandeel has constituted approximately two thirds of the total industrial fish catches. ICES estimates the average catch in the industrial trawl fishery for the five-year period 1987–1991 to be 1.30 million tonnes per year, including a by-catch of 0.17 million tonnes of species for human consumption (herring, whiting, haddock, saithe, and others).

Direct effects of fishing

Mortality

Fish

Current levels of fishing mortality of the most important commercially exploited fish species in the North Sea are summarized in Table 5·2. They are expressed as the percentage of the initial population present at the start of the year which is removed by fishing during the year (see Box 5·5). For cod

Table 5·2. Estimated percentage of stock caught during the year for the main fish species exploited in the North Sea, 1986–1990. Source: ICES (1994). The range of age groups to which the estimate applies is shown. 0 refers to 0-group fish in their first year of life, 1 to fish in their second year of life, etc.

	Juveniles		Main exploited age groups	
Species	Age	% caught	Age	% caught
Cod	1	11	2– 8	52
Haddock	1	5	2– 6	54
Whiting	1	12	2– 6	37
Saithe	1	2	2– 6	30
Sole	1	–	2– 6	33
Plaice	1	–	2–10	27
Herring	1	20	2– 6	29
Sandeel*	0	2**	1– 3	21
Norway pout*	0	3**	1– 2	17

* mean values for 1986–1989;
** estimates for the second half of the year.

and haddock these levels imply that more than half of the fish of exploited ages will be captured during a year. The fishing mortality of cod is very high, and moreover, juvenile age groups are exploited at a high rate. Cod are caught when they reach the age of approximately two years. About 70% of the two-year-old cod are removed from the population before they begin to mature at three years of age; of these about 80% are caught and 20% die from natural causes (chiefly predation). In the case of whiting, saithe, sole, plaice, and herring, approximately one third of the fish of exploited ages will be caught, while for sandeel and Norway pout, which are exploited by the industrial fishery, one fifth will be captured. Except for haddock and whiting, the estimates of fishing mortality do not include fish that have been thrown overboard. No estimates are available on the fishing mortality of non-commercial species of fish.

Some fish are also damaged or killed and left in the path of the gear during its deployment. The total quantities that die from this cause cannot be assessed, but they are presumably small compared with the catches.

Benthos

In the case of benthos, towed fishing gears in contact with the seabed cause the mortality of infauna and epifauna. Infauna are most affected by gears or gear parts that penetrate the seabed, such as beam trawls or the otter boards of bottom trawls. Depending on the type of substrate, beam trawls may penetrate the sediment to a depth of 6 cm or more. The mortality of animals left in the path of beam trawls has been estimated for a limited number of species and ranged from 15 to 55%. Among the benthic animals caught in beam trawls, the mortalities range from virtually zero to almost 100%, depending on the species. Epifauna are affected by all towed demersal fishing gear, but insufficient information is available on the relative catchabilities of different species in different types of gear.

The conversion of per cent mortality in the trawl path into estimates of overall mortality is problematic because it requires estimates of the spatial distribution of both the gear deployment and the benthic species. However, estimates of the total areas swept annually by beam trawls and otter boards can be made (Figure 5·6). These estimates indicate that some fishing grounds in

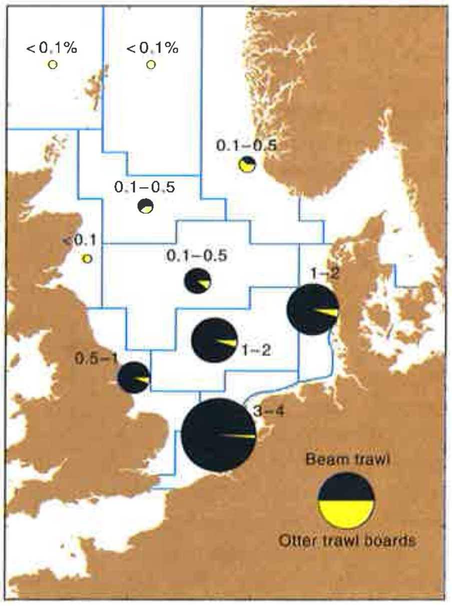

Figure 5·6. Total area swept in 1989 by gears that penetrate the sediment, relative to the size of the corresponding NSTF areas. Source: ICES (1994).

Table 5·3. Discard rates. Estimated percentage by weight of fish and other material discarded in some of the main fisheries, 1987–1989. Source: ICES (1994).

		Percentage of fish captured that are discarded			Additional percentage of other material*
Area	Gear	Commercial species	Non-commercial species	Total	
Western and north-western North Sea	Trawl	45	7	52	n.i.
Eastern North Sea	Seine	49	6	55	n.i.
Southern North Sea	Trawl and seine	12	15	27	9
	Beam trawl	18	38	56	58

*Quantity expressed as percentage of combined catch of fish and benthos; includes benthos and inorganic matter. n.i.: no information.

the southern North Sea are likely to be swept more than three times a year by gears that penetrate the seabed. They also indicate that the major impact is from beam trawls. Swept-area estimates should not, however, be used as an estimate of the area of the North Sea that is affected by trawling. The application of fishing effort is very uneven, and certain areas will be fished many times while other nearby areas may be completely missed. Data with adequate spatial resolution are currently lacking.

Seabirds

There are many observations that attest to the death of seabirds from entanglement in fishing gear. Evidence suggests that the heaviest impact is caused by gillnets and other fixed nets that can entangle diving seabirds. The impact cannot be quantified at present. It is thought to be sporadic and localized.

Marine mammals

Most by-catch problems in the North Sea seem to involve small cetaceans such as harbour porpoises and bottlenose dolphins rather than seals. Harbour porpoises are caught in gillnets (Reijnders, 1992). Although estimates have been made of the number caught in certain fisheries, they are not considered reliable because they are based on small samples. The data are thus not adequate to quantify the resulting mortalities.

Seals can also become entangled and killed in fishing gear. There is evidence that fixed nets near major colonies are mainly responsible. In some countries it is legal to shoot seals if they interfere with fishing gears. The resulting mortalities have not been quantified.

Discards and offal

Fish and benthos that are caught and thrown back into the sea are known as discards. In fisheries that target species for human consumption, fish may be discarded for regulatory reasons (undersized or over-quota fish), because no market for them exists, or to maximize the value of the catch (known as 'high-grading'). Discarding is especially prevalent in mixed fisheries, i.e., those 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. Discarding by the industrial fishery is considered unusual.

For haddock and whiting caught in demersal fisheries in the northern North Sea, the discards amount on average to one third of the weight of the catch. For other fisheries, species, and areas, fewer data are available, and only approximate discard rates can be derived (Table 5·3). These rates are in line with those estimated in a limited Dutch experiment and, although the data do not allow a global estimate to be made, they suggest that in certain fisheries more than half of the fish caught and considerable amounts of benthos are discarded annually. Some of the discarded animals survive, but many are dead or dying. In addition to the discards, fish species used for human consumption are often gutted at sea. The resulting offal corresponds to approximately 12% of the weight of landings of fish that are gutted.

Discards and offal provide a source of food for a number of seabird species such as fulmars, gannets, great black-backed gulls, and great skuas. Fish and benthos that have been damaged or killed by fishing gear (although they have not been caught) add to these inputs; they will be more available to benthic scavengers than to birds.

Physical disturbance of the seabed

Towed fishing gears such as bottom and beam trawls may change the seabed physically, but the nature of the effect will depend on the gear and the kind of substrate. Heavy towed gears can change the sediment characteristics of the seabed, displace boulders that form a primary substrate for benthic organisms, and mobilize sediment particles, leading to transport of fine particulate matter and modification of sediment geochemistry, including the sediment–water exchange (e.g., of nutrients and contaminants).

Production of litter

Fishing operations generate litter through the accidental loss of gear and the dumping of damaged gear. Fisheries-derived litter can be a significant part of the litter found on the sea floor. Like most other vessels, fishing vessels are responsible for discarding general refuse material such as bottles and plastic, which end up on the sea floor or on beaches.

Longer-term effects

Effects on fish

The additional mortality imposed by fishing typically leads to a shift in the age composition of fish as older and larger individuals are removed. As a result the proportion of mature individuals in the population will decrease.

Despite heavy exploitation of fish species taken for human consumption during most of this century, there are only a few population collapses that can be directly linked with fishing (see Box 5·5). The decline in the North Sea mackerel stock in the 1960s was almost certainly caused by very heavy fishing. Since then the spawning stock biomass of mackerel in the North Sea has remained at a very low level (egg production in 1986 is estimated at about 2% of the mid-1960s value), despite the fact that fishing mortality of the stock has been effectively reduced. However, in recent years the Western mackerel stock has been invading the North Sea during feeding migrations, and during much of the year the amount of mackerel actually present in the North Sea is not very different from that of the period before 1965. The collapse of the North Sea herring stock has been linked to over-harvesting, but the recruitment failure that followed has been explained by anomalies in the North Sea circulation that affected recruitment as well as by a reduction in spawning stock biomass. Regardless of the cause of the stock declines, exploitation requires even more careful control during periods of decreased recruitment. Fortunately, this is made possible by the advance warning of recruitment fluctuations available from the international young fish surveys carried out in the North Sea. Haddock and cod have recently reached their lowest level of spawning stock biomass in the past 30 years as a result of high fishing mortality and poor recruitment, and this gives reason for concern (Heessen, 1988).

For the short-lived fish species exploited by the industrial fisheries, far fewer data are available. These species constitute an important source of food for a number of other species, and changes in their abundance may thus have important direct and indirect consequences.

No firm conclusions about the impact of fishing on the non-commercial species of fish can be made. There are reports of local declines in catches of a number of species in parts of the southern North Sea, but whether these are indicative of more general declines in abundance and whether they are related to a change in or intensification of fishing in the area is not clear. Among the elasmobranchs, of which many have a low fecundity, the reported landings of some species of rays (e.g., the skate, *Raja batis*) have shown a steadily declining trend over most of this century. In contrast, the landings of sharks showed a remarkable increase after World War II, and they have only recently declined.

In principle, fishing acts as a selective force and is therefore likely to affect the genetic composition of a population. Such genetic changes may become apparent in life-history parameters (e.g., growth rate or age at maturity). A thorough review of the available information on North Sea plaice indicates that about half of the observed changes in size at first maturity may be explainable as a response to changes in environmental conditions, but the other half may well be caused by changes in the genetic composition of the population. However, because both genetic composition and environmental conditions play a role in shaping growth and maturation patterns, it will be very difficult to provide the ultimate proof of the significance of genetic effects of fishing.

Effects on benthos

Consideration of the biology of many benthic species suggests that although populations are directly affected by the fisheries, they are unlikely to suffer from recruitment failure at current levels of fishing. The reason for this is that, as with many species of fish, benthos have a vast production of eggs and larvae which, as a result of dispersal, are capable of regenerating the population even when it is at a relatively low level.

On local scales, particularly in inshore habitats, there are cases of loss of target populations, such as oysters, and destruction of reefs built by species such as the polychaete worm *Sabellaria* sp. or by calcareous algae. In these cases fishing has led to structural changes in the habitat and changes in species assemblages. The evidence for more widespread and general effects is unclear, and the extent to which changes have occurred cannot be assessed at present owing to the lack of appropriate large-scale time series of data.

Some communities may be more vulnerable to physical disturbance than others. Inshore communities inhabiting sandy substrates in exposed areas would generally be expected to be the most resilient, while the fauna of stable deposits (inshore and offshore) may be expected to be more sensitive, because of their prolonged rates of recovery due to the longer life spans and intermittent recruitment success of a number of the characteristic species.

It has been suggested that fisheries-generated mortality would result in a general reduction in the abundance of long-lived species, leading to replacement by short-lived, faster growing species whose populations may be better suited to responding numerically to continued disturbance. The burrowing sea urchin *Echinocardium cordatum* and the bivalve *Arctica islandica* are two abundant long-lived species for which high trawl-path mortalities have been reported. *A. islandica* has been reported to be able to live for 100 years or more, while *E. cordatum* has an estimated life span of five to ten years. Swept-area estimates, such as those presented in Figure 5·6, suggest that the scale of fisheries-generated mortality should be sufficient to cause a significant reduction in the abundance of these species in the southern North Sea. Nevertheless, as shown in Figure 5·7, both *E. cordatum* and *A. islandica* were surprisingly common in the southern North Sea in 1986. Their widespread distribution despite an intensive fishery runs counter to predictions about the response of benthic communities to fisheries-generated disturbance and mortality and illustrates the lack of scientific understanding of the problems involved. Undisturbed reference sites are not available, and areas closed to fishing for purposes of scientific investigation would facilitate an understanding of the relevant processes.

Effects on seabirds

Time-series data for many seabirds go back to the beginning of the century and show large increases in the populations of several species. There is no evidence that mortality due to entanglement in gillnets has hampered these increases, even at a colony level. For

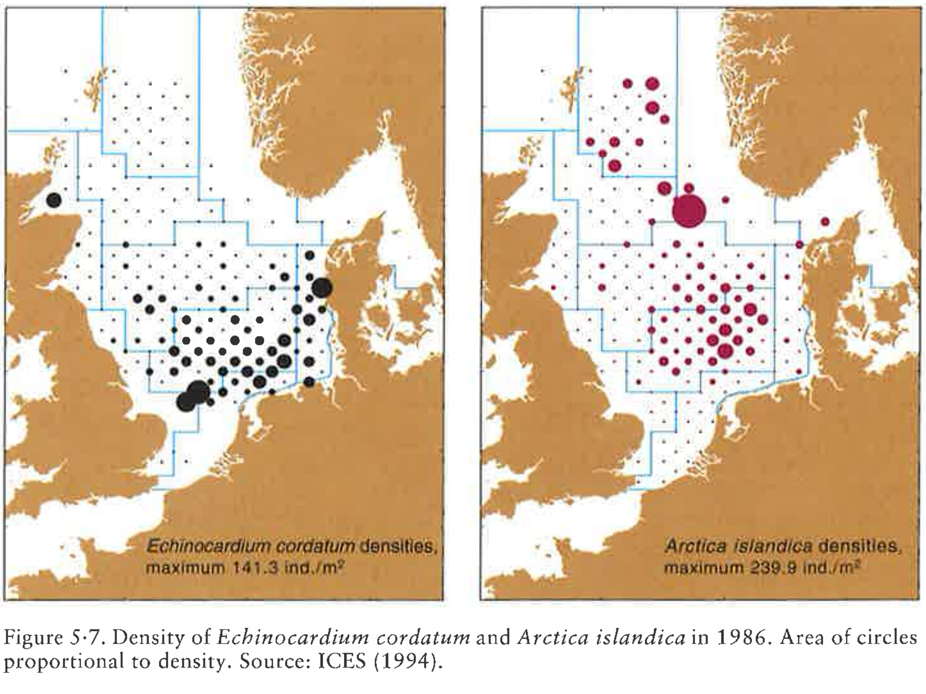

Figure 5·7. Density of *Echinocardium cordatum* and *Arctica islandica* in 1986. Area of circles proportional to density. Source: ICES (1994).

some of the species the increases have been attributed to increased food supply from offal and discards from fisheries, but decreases in hunting pressure and the introduction of protective measures in nature reserves may also be involved.

Observations in the North Sea have shown that at various times of the year, fulmars, large gulls, gannets, great skuas, and kittiwakes have distribution patterns closely associated with fishing-vessel itineraries. Studies at Shetland and in the southeastern North Sea have shown that a high proportion of discards may be taken by seabirds. It is impossible to tell how representative these studies are, but it has been estimated that discards and offal have the potential for covering a large proportion of the food requirements of some of the species.

Fisheries may compete directly for the same prey as seabirds. In the Wadden Sea, inshore fisheries for mussels and cockles compete with bird populations feeding on these shellfish. In the North Sea, sandeels and sprat are taken by many birds as well as by industrial fisheries. At Shetland, declines in the breeding success of a number of seabirds during the 1980s have been related to a significant decline in sandeel recruitment (Box 5·6). The local stock of sandeel was exploited by a small industrial fishery, and the decrease in sandeel recruitment was at first believed to be related to overfishing. However, the spawning stock biomass of sandeel remained high throughout the 1980s, and the recruitment failure, and corresponding losses of food to seabirds, cannot be shown to be a consequence of fishing. Rather, hydrographic influences seem to be implicated. Recruitment of sandeels and seabird breeding success improved dramatically in 1991.

Changes have also been observed in the at-sea distribution of seabirds that appear to be related to changes in the abundance and distribution of their prey. There is, however, no evidence that these changes have been caused by the industrial fisheries.

Effects on marine mammals

The trend in grey seal populations since 1965 shows that they have been either stable in size or increasing. Populations of harbour seals increased up to 1988 when a sharp decline occurred owing to a disease epidemic caused by the phocine distemper virus; thereafter, populations began to increase again from their depressed 1988 level. Seal populations have thus remained stable or increased, although subject to fisheries-induced mortality.

The impact of fishing is uncertain in the case of cetaceans owing to ignorance of their distribution, abundance, and mortality rates. Clearly a better understanding of their population dynamics is needed. An analysis of sightings indicates that the harbour porpoise is no longer seen frequently in the Wadden Sea and the southern North Sea. However, it is still common in winter along the northern Dutch, the German, and the Danish North Sea coasts, and in summer on the east coast of England. Concern has been expressed about the effects of high contaminant levels, disturbances, changes in the availability of food, and by-catches. It is difficult to assess the current health of the harbour porpoise populations in the southern North Sea, but the relatively low lifetime reproductive output of this species renders it vulnerable to additional mortality. Further data on by-catches and abundance are therefore urgently needed.

5.5. Habitat changes

Introduction

The North Sea, including its coastal zones, provides a rich diversity of habitats for biota, which are affected by human activities in many ways: by coastal protection and sea defence measures, land reclamation, industrial and harbour installations, dredging or extraction of sediments, disposal of wastes and dredged material, mariculture operations, recreational activities, military activities, etc. A complete inventory of activities and, above all, a description of their effects on the ecosystem, is not possible. Within the complexity of causes and effects involved, general or more local interferences can, however, be distinguished even if the range of ecological effects is difficult to describe in detail. In several countries, coastal planning and regulation is carried out with the aim of making more rational use of the coastal zone.

Disturbances and effects of human activities may be permanent (e.g., effects of land reclamation) or temporary (e.g., physical effects of bottom trawling) and can be categorized as resulting in: changes in habitat size, or changes in habitat conditions, or combinations thereof.

A general geographical pattern is reflected in the North Sea. It is quite clear that human interference increases, moving southwards in the North Sea.

Changes in habitat size

Construction of coastal industrial structures and harbours inevitably affects ecological processes and leads to a definite elimination of breeding areas, to destruction of habitats, and to loss of biotopes. This pattern is repeated along all North Sea coasts.

There are several very clear examples of engineering works resulting in loss of habitats. One of the most notable alterations has occurred in the Wadden Sea as a result of activities carried out for purposes of agricultural land reclamation, sea defence, harbour construction, and industrial settlement. Although new salt marshes may be created, the overall area of salt marshes has been considerably reduced and hardly any natural saltwater/freshwater transitional zones remain.

The Belgian and Dutch coastlines have also been very much affected by coastal protection and land reclamation activities, especially in the delta region of the Rhine, Meuse, and Scheldt: habitats have changed or disappeared, but new ones have also developed. In the Eastern Scheldt, the area of tidal flats has been reduced owing to construction of a storm surge barrier, leading to a reduction in the number of wading birds. In the Rhine/Meuse delta (and especially in the Eastern Scheldt), shrimp populations have decreased following the loss of nursery grounds. This decrease is partly compensated by an increase in the coastal area known as the 'Voordelta', where a new transitional habitat is developing as a result of a raising of the outer sandbanks.

The coastal protection programme for the east English cliff coast aims at preventing erosion by the sea. Natural mobility and degeneration of cliff slopes are being prevented and sediment longshore drift restricted. The restriction of sediment drift may influence natural coastal protection features such as the forming of beaches and sand dunes. Conservation measures along the flat alluvial east English coast were introduced already in Roman times. The activities, which were and still are carried out for agricultural, recreational, and safety reasons, have caused a narrowing of the foreshore and consequently a change in habitats.

With the exception of the petrochemical complex at Sullom Voe and the harbour of Lerwick, the north and east coasts of Scotland are not influenced by anthropogenic modifications.

The Skagerrak and Kattegat regions are still relatively natural and no major land reclamation projects have taken place in recent years.

Changes in habitat conditions

Changes in climate can be regarded as one of the overriding potential threats of the coming decades, with the possibility of major impacts on the whole ecosystem of the coastal margin, for example, through changes in sea level. The effects will be most obvious in lowland and tidal-flat areas.

Changes in habitat conditions are very often a result of disturbance by human activities and will mainly result in temporary effects. When the cause of disturbance disappears, recovery may take place, although it may stretch over several years.

Such disturbances may be the result of:

- extraction of bottom material (e.g., dredging, sand and gravel extraction) or burial of the bottom by disposal of solid material (dumping);
- changes in water balance, current regimes, etc.;
- the mere presence of human beings (recreation);
- noise (offshore activities, shipping, and military use).

Sand and gravel extraction takes place in many different areas but most intensively in the southern North Sea (Subregions 3b, 4, and 10). Roughly four times the amount of sand extracted is put in suspension. Therefore, the obvious effects on the benthos are caused by both the extraction process and increased sedimentation. Studies have shown that biomass can be reduced by 80% following extraction activities, and complete recovery of the benthos may take ten years or more. In the Wadden Sea, extraction has had a much greater impact in the intertidal area and the shallow gullies than in deeper gullies. Extraction sites were filled up very slowly, and the bottom fauna were not yet restored after 15 years. Large, long-lived bivalves were particularly affected.

In Belgian and Dutch coastal areas, dredging to maintain harbours and navigational channels leads to a segregation of sand and mud and therefore has a significant impact on near-shore sand shortage and mud enrichment. In these areas, the total size of the seabed that has been changed as a result of dumping of dredged spoils is estimated to exceed 1000 km^2. The high nematode/copepod ratios found in the meiobenthic community may have been caused by this dumping. In addition, dumping results in increased turbidity and consequently reduced light availability, which in turn affects phytoplankton growth and the behaviour of fish and birds.

In the Wadden Sea, large-scale dredging interferes with hydrological and geomorphological processes and affects turbidity. It is unclear to what extent dredging activities contribute to temporary or structural changes in suspended matter concentrations and turbidity in the Wadden Sea as a whole. However, it is clear that dumping of spoils just outside the dykes has resulted in alterations to or destruction of the natural biotopes.

Mining and industrial wastes have been disposed of in, for example, the German Bight and Humber Estuary. Here local effects on the benthos have also been observed. There is no evidence that regional-scale effects are caused by such activities.

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, i.e., the timing and development of algal blooms. 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.

Recreational activity may interfere with the natural functioning of the coastal zone as a habitat. Through recurrent disturbance, specific areas may become unsuitable for the breeding, resting, or feeding of marine organisms. Disturbances during critical periods of this kind can reduce the viability of the animal population concerned by lowering reproductive success and by increasing mortality. For example, in some areas along the east coast of England, particularly in peak summer months, there is a direct conflict of interest. Similar problems occur elsewhere.

The coastal areas of Belgium, Denmark, Germany, and the Netherlands are among the most important recreational areas of the North Sea. The main tourist season coincides with the breeding season for both birds and seals; and the biotope for birds breeding on sandy beaches has been almost completely lost owing to recreational activities. Disturbance by large numbers of tourists in small boats or on surfboards is probably one of the main causes of the disappearance of the harbour seal in the Dutch delta region in summer. The high recreational pressure in the Wadden Sea is regarded as one of the major sources of disturbance (Tasker and Becker, 1992).

Activities such as shipping, offshore mining, and military use lead to mechanical, visual, and acoustical disturbances. Effects on the ecosystem are uncertain. Observations in wildlife reserves in the Wadden Sea have led to the conclusion that air traffic (especially by 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.

5.6.

Microbiological quality, algal toxins in seafood, and other effects on human health

Introduction

This section will focus on potential effects on human health. Two main areas with a bearing on human health can be distinguished: the microbiological quality of bathing water, and the quality of seafood, mainly shellfish.

Bathing water quality

The microbiological quality of bathing water has been monitored for many years in various countries around the North Sea. One of the first directives of the European Economic Community in the environmental field concerned the quality of bathing water (76/160/EEC) and was adopted in December 1975. The legislation is binding on Community member states. Sweden and Norway have adopted similar but stricter legislation.

In the execution of the directive, each member state is requested to submit annual reports to the Commission of the European Communities on the monitoring of the quality of its bathing waters. Subsequently, the Commission publishes a combined summary report of the monitoring results. The contents of these annual EEC reports and results from other countries are very often understood by the public as providing a way of ranking the bathing water quality in different regions. This interpretation is quite erroneous for several reasons:

1) the EEC directive provides a framework of quality standards, but member states have some freedom of choice respecting establishment of their own standards within that framework;
2) moreover, there is some room for different interpretation by member states of the requirements of the directive, for example, regarding the conditions under which measurements of salmonellae (and enteroviruses) should be made;
3) different methodologies (methods of sampling, sample storage time, and analytical procedures) are used in various laboratories, and this is prejudicial to a direct comparison of results from different countries.

In order to overcome methodological difficulties, a number of studies are being undertaken to compare the results of different methods of analysis of standard seawater samples. Further international standardization of methods is obviously needed before a definitive comparison of results on a quantitative basis can be made.

Moreover, the nature of contamination by bacteria is specific to a local area and subject to great variability. The concentration of bacteria in coastal waters is heavily influenced by the size of the human population giving rise to sewage and other discharges and the type of treatment applied in sewage plants. In addition, diffuse discharges from agricultural areas and run-off by storm water, etc., may also seriously influence the quality of water. Bacteria in marine waters are also affected by temperature, light, and the dilution of saline waters within the mixing zone, which in turn is influenced by wind, currents, tides, and other factors.

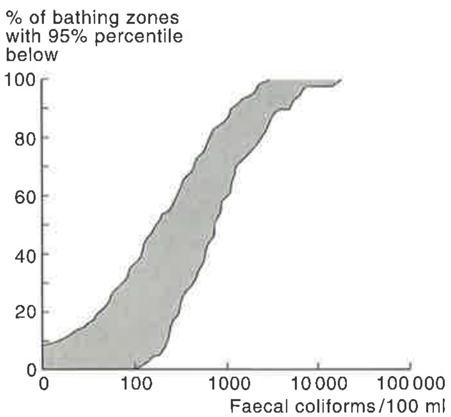

Figure 5·8. Envelope of cumulative graphs of 95 percentiles (upper extreme tendency) for faecal coliform concentrations (per 100 ml) in sea water, in Subregions 3a, 3b, 4, 9, and 10.

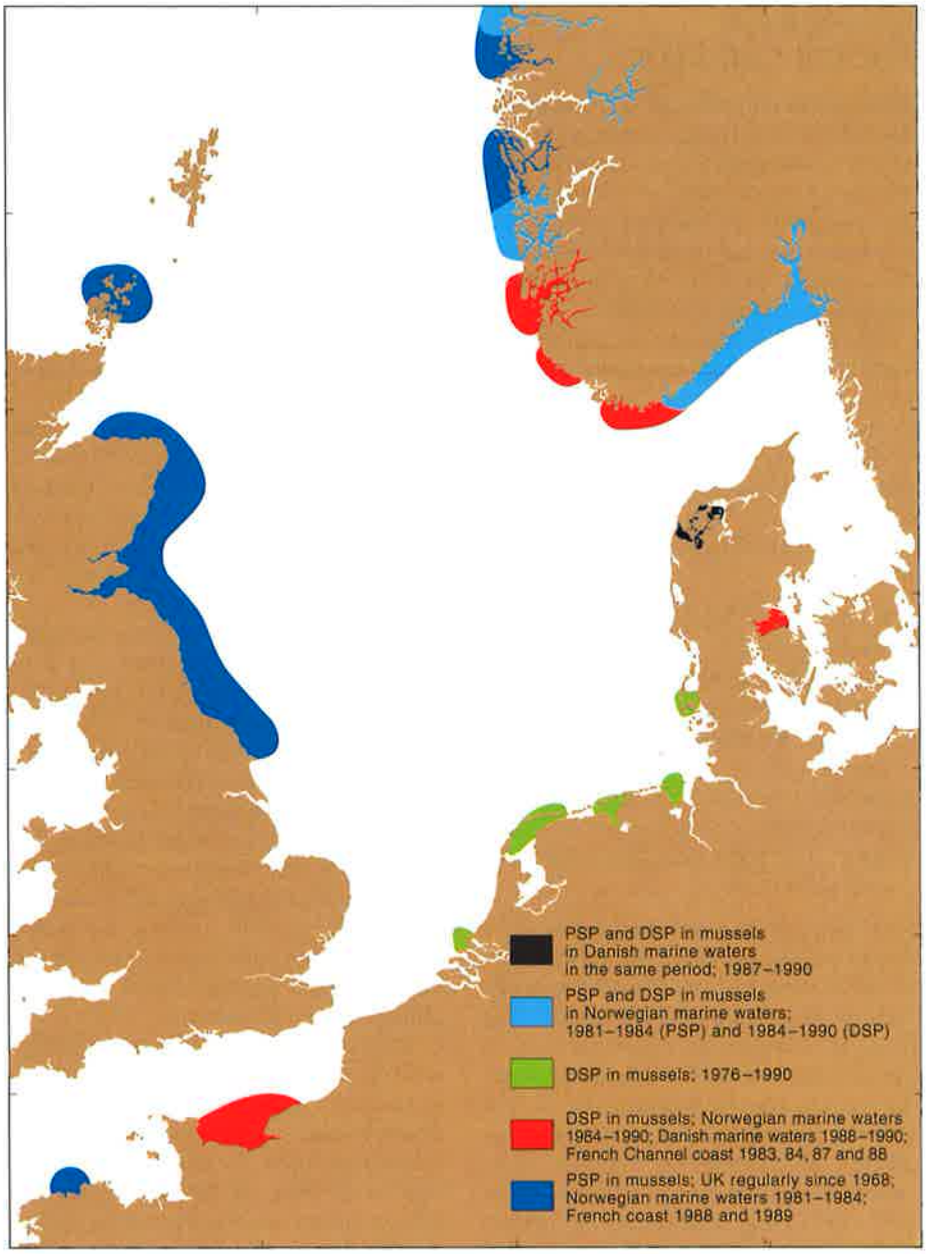

Figure 5·9. Occurrence of Diarrhetic Shellfish Poisoning (DSP) and Paralytic Shellfish Poisoning (PSP) in mussels in summer/autumn during various periods. Source: OSPARCOM (1992).

Despite all these known difficulties, the North Sea Task Force undertook to compile results of faecal coliform measurements in coastal bathing waters for the year 1990. Figure 5·8 gives the envelope of the cumulative graphs of 95 percentiles of all the bathing zones in Subregions 3a, 3b, 4, 9, and 10. The other subregions have not been considered because the raw data were not available or were considered to be statistically deficient. The figure indicates that 75–90% of the bathing zones comply with the EEC imperative value for faecal coliform concentrations (2000/100 ml).

This figure also reveals differences (about one order of magnitude) between the subregions. It is unclear whether such variations are explicable in terms of analytical differences only. This question will need to be resolved before progress can be made on international intercomparison and standardization of methods. It will certainly be necessary to understand methodological variability if real differences in bathing water quality are to be distinguished.

Quality of seafood

The EEC Directive 91/492/EEC lays down health conditions for the production and marketing of live bivalve molluscs intended for immediate human consumption or for further processing before consumption. This became operative in January 1993 and supersedes national regulations. Some aspects of this directive also apply to other edible marine invertebrates. Permissible limits are given (quantitative and qualitative) for, e.g., the numbers of faecal coliforms in mollusc flesh and intra-valve liquid, and the content of *Salmonella*. For the toxins produced by dinoflagellates that accumulate in bivalve molluscs, particularly the blue mussel, a qualitative standard based on the bioassay of choice is applied to Diarrhetic Shellfish Poisoning (DSP) caused by *Dinophysis* spp. For Paralytic Shellfish Poisoning (PSP) caused by dinoflagellates of the genus *Alexandrium* (formerly *Gonyaulax* and *Protogonyaulax*), a more dangerous phenomenon since it has caused human deaths, a standard of 80 µg per 100 g of edible meat is applied in the standard bioassay method using mice. Similar regulations exist in Norway and Sweden. Figure 5·9 shows areas in which PSP and DSP toxins have been found in mussels in recent years.

In the Skagerrak and Kattegat the content of colibacteria is a minor problem; however, accumulation of algal toxins has created some problems for the mussel industry and sport fishing. 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. Nevertheless, along the southern Norwegian coast, owing to the persistent occurrence of *Dinophysis* spp. and the resulting protracted closures, the mussel farming industry has been in effect destroyed. The problems are somewhat less severe in Sweden and Denmark but underline the importance of a mandatory surveillance programme.

In the Dutch area of the Wadden Sea, DSP infection has been recognized since 1976, and ten years later it was found in German and Danish waters. The frequency of reports of occurrence of DSP is increasing. Until now, PSP has not been recorded in the Wadden Sea, but blooms of a producer of PSP toxins, a dinoflagellate planktonic algae, are now widespread in Danish and German Wadden Sea waters and appear to be spreading southwards; this has been linked to increasing eutrophication.

The standard for thermotolerant coliform bacteria in shellfish meat has been exceeded only in the eastern part of the Western Scheldt Estuary, which has led to its closure as an area for shellfish production.

Along the French coast of the Channel a monitoring network alerts local authorities when sanitary standards are exceeded, to guarantee the safety of human consumers of shellfish. Bacteriological and algal toxin levels are determined by French laboratories that inform the authorities when marketing of shellfish needs to be prohibited. Along the French Channel coast, and in particular in Normandy and Picardy, some shellfish purification plants are in operation. The number of these plants is likely to increase with the application of EEC Directive 91/492/ EEC.

Along the United Kingdom coast the application of control measures has been governed by domestic legislation enforced by local authorities. The important requirement for classification is the faecal bacteria content of shellfish flesh. Algal toxins are determined by a central laboratory. Most shellfish production is subject to post-harvest processing to reduce microbial contamination. The cockle fishery in the Thames Estuary is covered by a statutory order that stipulates cooking before consumption.

In some areas pollution raises concentrations of chemical contaminants in organisms to such high levels that authorities responsible for public health protection have placed restrictions on the use of these areas as sources of seafood. There are restrictions on human consumption of fish and shellfish from the Frierfjord and the Kristiansandfjord in Norway because of high levels of organochlorines and from the Elbe Estuary because of high levels of mercury.

5.7. Effects of litter

Litter is widespread in the North Sea, but only a few studies on distribution and effects have been conducted. The main sources are shipping and tourists on beaches, but rivers and dumping of sewage sludge are also significant contributors. Packing materials, lost fishing gear, and raw plastic pellets are the principal offenders. Plastics constitute most of the material. In 1988, during a Dutch survey, large amounts of litter were observed on the bottom and along the shores of the southern North Sea and the German Bight, e.g., 350–700 kg/km^2 caught by bottom trawl on the seabed of the Dutch continental shelf. There is also a great deal of floating material. A survey carried out in 1987 showed a mean density of about 9000 kg/km^2 of litter on the Dutch shore, of which about 70% originated from bathers while the remaining 30% had been washed ashore (Wolfe, 1987).

Entanglement and drowning of birds, in particular gannets, and marine mammals in lost fishing gear (sometimes termed 'ghost nets') occur regularly in the North Sea. The impact on bird and mammal populations is not known. At Helgoland at least 2.6% of 313 gannets observed were entangled in fragments of fishing gear, while entanglement accounted for the death of 7 of 23 gannets found on the beach.

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 can accumulate in the gizzard of this species. It has been suggested that this phenomenon has increased rapidly over the last two decades. Chicks of seabirds 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 the limited regurgitation by the chicks.

Dumped ammunition and various warfare gas canisters constitute a special type of litter. In the Skagerrak, for example, the dumping sites of two major releases of gas canisters have been identified (Sjöfartsverket, 1992). Danger to humans and possible ecological effects are largely uncertain, but they are considered to be minor because of the effects of hydrolysis and rapid dilution.

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CHAPTER 6

Overall scientific assessment

6.1.

Introduction

The material on which this chapter is based is drawn mainly from the preceding five chapters. In principle all the subregional assessment reports were to follow the same format and cover the same topics, but for several reasons not all did so to the same degree. In consequence, information may be available for only one area or a limited number of areas, although problems may be associated with other areas as well. In such cases, the text makes it clear when information was available, or was not available, for particular areas.

As the title of the chapter implies, its purpose is to provide an overall summary of the physical, chemical, and biological status of the North Sea. Where gaps in knowledge are apparent, they are mentioned under the appropriate subheadings. However, the main emphasis is on the problems that exist and the identification of causes, particularly those attributable to human activities. Two factors must be kept in mind while reading this chapter: the variability in the extent to which data were available, and the natural variability encountered in the marine environment.

Although it is well recognized that the North Sea is not spatially homogeneous and that conditions change with the seasons, it is generally less well understood that there are marked variations from year to year. Short-term spatial and temporal patchiness also occurs on less than seasonal scales. This natural variability makes it difficult to identify trends over time with any certainty, and attributing causes to the effects observed is an even more uncertain process. The role of natural variability is particularly well documented for physical characteristics (see Chapter 2), but it is just as important for biological characteristics, which may be determined by purely biological factors, but are also profoundly affected by even relatively small changes in the physical environment. For example, as a result of natural changes in the precise location and flow of a current, conditions that affect recruitment success for a fish stock may be enhanced or worsened. Accordingly, where such natural factors are believed to play a role in causing a detected change, attention is drawn to this fact.

The concluding section of this chapter addresses issues of concern and identifies major gaps in knowledge about the North Sea; some suggestions are made as to how these may be reduced. Chapter 7, in contrast, presents a number of possible solutions to problems caused by human activities that interfere with the natural functioning of the North Sea ecosystem. In view of the difficulty of attributing causes to observed effects, the final chapter points to the need for conducting risk assessments rather than engaging in what may prove to be a fruitless search for scientific proof.

6.2.

Habitat changes and physical disturbances

Introduction

Human activities carried out in or along the North Sea that are the source of visual, mechanical, and acoustic disturbances may directly affect the marine ecosystem. The disturbances and their associated effects may be either temporary or permanent. Land reclamation and coastal construction works, for example, cause permanent destruction of habitats, whereas the effects of dredging, such as increased turbidity, are of a more temporary nature.

This section presents an overview of the disturbances caused by human activities in and around the North Sea. The chemical aspects are covered in Sections 6.4 and 6.5. Alterations in offshore habitats may be caused by fisheries and offshore mining: the effects of fishing on the ecosystem are addressed in Section 6.3, and the effects of offshore mining are covered in 'Changes in habitat conditions' (p. 100).

Most of the information on habitat changes and physical disturbances was presented in the assessment reports for Subregions 4 and 10 and, to a lesser extent, in those for Subregions 2a and 3a. Little or no information was presented for other subregions.

Changes in habitat size

The natural habitats in coastal areas of the North Sea are integral components of the North Sea ecosystem. Many species spend parts or all of their lives in these habitats. Specific features of the coastal zones include high primary production, breeding and moulting sites for birds and seals, and nursery grounds for some fish species. Coastal protection works, land reclamation activities, and the construction of harbours and industrial and tourist facilities have resulted in a loss of marine habitats. This loss is most pronounced along the southern and eastern North Sea coastline stretching from northern France along the Belgian, Dutch, and German coasts, and northwards along the Danish west coast.

Large areas of salt marshes and sandy beaches have disappeared, and very few natural freshwater/saltwater transitional areas and natural estuaries remain. If the sea level rises as a result of climate change, additional subtidal and shallow areas may be lost. Agricultural, recreational, and coastal defence projects on the alluvial east coast of England have led to a reduction in the width of the foreshore and consequently a loss of habitats. The coastal areas of northern England, Scotland, Sweden, and Norway are still relatively unspoiled.

Changes in habitat conditions

Changes in habitat conditions may result from disturbances caused by such human activities as extraction of aggregates (sand, shells, gravel), recreation, shipping, and industrial and offshore development. Most of these types of activities are carried out throughout the North Sea, but they are particularly intensive in Subregions 3b, 4, and 10.

Through sand and gravel extraction, sand is resuspended and the seabed is disturbed. These disturbances have a negative effect on benthic communities. Dredging activities in the Belgian and Dutch coastal zones and in the Wadden Sea increase turbidity and affect the sand and mud balance.

The construction of hydroelectric power stations has altered the pattern of freshwater flow, water exchange, and the saline layer, as well as often markedly reducing the spring flow. Some of the consequences are understood, e.g., the timing of spring algal blooms in Norwegian fjords, but the wider implications of biological changes are unknown.

Recreational activities are very intensive along the Belgian, Dutch, German, and Danish coasts, and the main season for tourism in these areas coincides with the breeding seasons for many birds and seals. Since the animals are extremely susceptible to disturbances at this time, recreational activities have in effect destroyed the sandy beach breeding biotope for birds along this stretch of the coast. The establishment of nature reserves around the North Sea may help to compensate for these losses.

Activities such as shipping, offshore mining, civil and military air traffic, and military ground exercises cause mechanical, visual, and acoustical disturbances. Little is known about the precise nature or scale of the effects of these disturbances on the marine ecosystem.

6.3.

Fisheries and mariculture

Introduction

The various species of fish found in the North Sea differ widely in abundance, and it is estimated that fewer than 20 species make up over 95% of the total fish biomass. Many of these species are the target of commercial fisheries. There are also commercial fisheries for shellfish. Norway lobster, blue mussels, cockles, and brown shrimp are the most important shellfish species.

Along the west coast of Norway there are more than 400 fish-farming units, most of which rear salmon (total production 70 000 tonnes in 1990 in the North Sea). In the Wadden Sea and the Dutch Delta mussels and oysters are farmed. Similar shellfish cultivation operations are found along the coast of France, particularly in northern Brittany, and to a lesser extent for oysters on the southeast coast of England.

From roughly 1900 to 1960, total fish catches in the North Sea increased gradually from about one million tonnes to about two million tonnes. During the 1960s the catch increased steeply to approximately 3.5 million tonnes, followed by a gradual decline in recent years to about 2.5 million tonnes. Half the total catch is accounted for by industrial fisheries (harvesting small fish for reduction into fish meal and oil) that have developed since the early 1960s and have become responsible for a great many of the changes in total fish catches.

Total catches of Norway lobster vary from 6000 to 11 000 tonnes per year; catches of mussels, cockles, and brown shrimp were, respectively, 99 000, 17 400, and 27 300 tonnes in 1988.

Fisheries and mariculture have a number of direct and long-term effects on the ecosystem, as follows:

1) fishing causes mortality of target fish, by-catch species, and other non-target organisms;
2) fishing and mariculture may affect the food supply of other species;
3) some types of fishing gear disturb the seabed;
4) fishing generates litter;
5) mariculture may affect the genetic composition of wild stocks and introduce diseases and parasites.

These effects are briefly described in the following sections. It should also be noted that mariculture often involves the use of chemicals and increases the inputs of both nitrogen and phosphorus in particular, which can lead to local eutrophication and reduced oxygen levels.

Mortality

Mortality of fish

The current level of fishing mortality, expressed as the percentage of the population present at the start of the year which is caught, varies from about 20% (sandeel and Norway pout) to 50–55% (cod and haddock) (Table 5·2). The additional mortality due to damage suffered by fish escaping through meshes of the fishing nets has not been estimated, nor are realistic estimates available for the fishing mortality affecting non-commercial species as well as benthos caught accidentally as by-catch. Large amounts of fish, mostly dead or dying, are discarded in certain fisheries.

In the longer term the additional mortality imposed by fishing typically leads to a shift in the age composition as older and larger specimens are removed from the population. The proportion of mature fish in the population then declines (typical examples of affected species are cod and haddock), and changes may also occur in predator–prey relationships. In principle, fishing acts as a selective force and may therefore in the long term affect the genetic composition of the population. However, because both genetic composition and environmental conditions play a role in shaping growth and maturation patterns, it is very difficult to determine whether the genetic effects caused by fishing are significant. Despite the fact that fishing mortality rates in the North Sea are among the highest recorded in the world, there are only a few instances of demersal fish stocks collapsing (i.e., decreasing to a small fraction of their average levels) as a direct result of fishing. There is evidence that some species of rays, for example, have been seriously depleted. In the case of pelagic species, high fishing mortality rates combined with poor recruitment resulted in the collapse of North Sea herring and mackerel stocks in the 1970s, and the herring fishery was closed for four years. Natural variation in recruitment of young fish to the population is also important. As a result of high fishing mortality and poor recruitment, haddock and cod recently reached their lowest levels of spawning stock biomass in 30 years, which is a matter of concern.

Although major changes have occurred in the abundance of some stocks of short-lived species, the links with fisheries are uncertain because abundance is also influenced by fluctuations in recruitment and high levels of natural mortality (predation). For the short-lived fish species exploited by industrial fisheries, far fewer data are available. Since they constitute an important source of food for a number of other species, changes in their abundance may have important direct and indirect consequences.

The time series of available data indicate that there may also be changes in the abundance of non-commercial species. A decrease in landings of some long-lived species (e.g., rays) has been noted. The data are incomplete, however, so it is difficult to make generalizations applicable to the North Sea as a whole, and the overall impact of fishing on non-commercial species remains unclear.

Mortality of benthos

Towed fishing gear in contact with the seabed can increase the mortality of benthic fauna. Some fishing grounds in the southern North Sea are probably swept on average more than three times a year by gears that penetrate the seabed. Favoured trawl tracks will be towed much more frequently. The mortality of benthic species caught in trawls can be substantial (up to 100%), but most of them have such a vast production of eggs and larvae that they are unlikely to suffer from recruitment failure. The suggested shift in abundance from long-lived species to short-lived and faster growing species has not yet been confirmed. However, undisturbed reference sites are not available, and understanding of benthos mortality would be facilitated if suitable areas were closed to fishing and reserved for scientific investigation.

On local scales, particularly in inshore habitats, there are cases of target populations (oysters, for example) that have been lost, and of reefs and banks, built by species such as *Sabellaria* spp. or calcareous algae, that have been destroyed as a direct result of man's exploitation of these resources.

Mortality of birds and mammals

Seabirds and marine mammals can become entangled and killed in fishing gear, and it is likely that gillnets and other fixed nets have the greatest impact. Mortalities cannot be accurately quantified since the statistics available are too sparse to be representative, nor can the overall impact on population levels of birds and mammals be clearly established at present.

Other ecological consequences of fishing

Fish and benthos that are caught and thrown back into the sea are known as discards. Discards and offal are a source of food for a number of seabirds, and studies have shown that they have the potential for meeting a large proportion of the food requirements of some species.

Fisheries may compete with seabirds for the same prey. In the North Sea, sandeel and sprat are important food species for many birds, but they are also taken by industrial fisheries for conversion to fish meal and oil rather than being used for direct human consumption.

Changes in the distribution of birds at sea appear to be related to changes in the abundance and distribution of their prey, and there is no evidence that they are caused by commercial fisheries. In the Shetland Islands, the reduced breeding success of a number of seabirds in the 1980s does not seem to be attributable to fishing activities but to natural factors occurring during the early life history of sandeels.

On the other hand, it has been documented that shellfish fisheries in the Wadden Sea have played a part in the low breeding success of a number of bird species that feed on shellfish.

Seabed disturbance and litter

Towed fishing gears such as bottom and beam trawls may change the seabed physically, but the nature of the changes will depend on the gear and the type of substrate. Mussel and cockle fisheries may also affect sediment stability.

Fishing operations generate litter through the accidental loss of gear and the dumping of damaged gear. Seabirds, marine mammals, and fish may become entangled in discarded or lost nets and fishing lines. Fishing vessels not only discharge oily bilge waters but also generate litter comparable to that of general shipping, not all of which is returned to the home port, according to evidence from beach surveys.

Impact of mariculture on wild fish stocks

Salmon that escape from fish farms represent a potential problem for wild salmon stocks. A significant proportion of the salmon caught are estimated to originate from fish farms. There is concern that farmed salmon may cause genetic changes in wild salmon strains adapted to the particular local conditions of a given river. Furthermore, there is evidence that diseases and parasites of cultured fish may lead to severe infections in wild stocks.

6.4.

Sources and patterns of contaminant input

Details of the main sources of inputs and the areas affected by those sources are contained in Section 6.7. This section seeks merely to put the overall sources into context both in relative terms and in terms of the areas most affected. Table 3·16 gives details of the gross inputs of the main contaminants by type of source for the North Sea in 1990.

North Atlantic

Atlantic Ocean currents flowing through the Channel and around northern Scotland are the principal source of North Sea water. For nutrients the scale of inflow in volume and concentration is such that the gross input from the North Atlantic is a major influence on the overall concentrations that are found, particularly in the north and central North Sea, although elsewhere other sources of input are more important.

Atmosphere

As Table 3·16 shows, the atmosphere is a very important source of most contaminants in the North Sea. Distribution is so widespread that the entire area is affected to some extent. There are, however, differences in local distribution, and it is estimated that only about half the quantities of most contaminants deposited over the Southern Bight are deposited over the larger northern sectors, reflecting the fact that the major emission sites are found around the southern part of the North Sea.

Riverine and direct discharges

Rivers are the principal source of most contaminants. Both rivers and direct pipeline discharges introduce a wide variety of substances into the sea, ranging from biodegradable organic matter to inert solids, and in many cases including persistent organic contaminants and trace metals. Sewage effluents from human settlements reach estuaries and coastal waters after varying levels of treatment. About one third of the sewage discharged into the catchment area of the North Sea (including the discharges into rivers) receives no treatment. These sewage discharges may affect the hygienic quality of the environment as well as, more generally, the quality of habitats and the ecosystem. Depending on the level of treatment and sludge removal, considerable quantities of organic matter are discharged. Such biodegradable organic matter plays a direct role in biomass creation and can, under certain conditions, lead to oxygen deficiency. The quality of beaches and the quality of certain seafoods, particularly filter-feeding bivalves, can be adversely affected by poorly located outfalls discharging directly into estuaries or the sea.

Dredged material

As Table 3·16 shows, substantial inputs of metals are introduced into the marine environment through disposal of dredged material. A proportion of this input, in most cases unknown, is accounted for by part of the river input deposited in estuaries. As such, there is an element of double counting in the summation of riverine and dredged material loads. The anthropogenic component is not easily estimated, and the availability of trace contaminants in both the natural and anthropogenic components – as well as their subsequent biological significance – is not clear. It is, however, apparent that the more highly contaminated dredged materials do have adverse effects on animals in the area of deposition and that they are attributable to the contaminant burden. Efforts should be focused on seeking cost-effective reductions in such effects and on developing proposals for alternative methods of handling dredged material. As a matter of principle, high priority must be given to reducing the inputs of contaminants to the dredged areas.

Pending the successful achievement of that goal, there will be a need to assess the potential for harm of dredging operations. There is a clear need for realistic sediment bioassays and reliable standards for sediment quality. In most cases, dredging, extraction, and disposal have a physical impact on the seabed and locally enhance concentrations of suspended solids. Transport processes, particularly of the finer fractions by wave and tidal action and residual currents, may also have an impact. In enclosed waters the dredging of anaerobic sediments may adversely affect dissolved oxygen levels in the water column.

Industrial waste and sewage sludge

In line with commitments made to the Oslo Commission and at the Third International Conference on the Protection of the North Sea, the disposal of industrial wastes at sea and the disposal of fly ash ceased at the end of 1992. There is still some dumping of colliery waste off the northeast coast of England, but alternative options for disposal are being investigated. The United Kingdom has also declared its intention to phase out the disposal of sewage sludge at sea by the end of 1998.

Other sources

Although offshore regions are indirectly affected by the sources of input discussed above, they are directly affected only by certain activities. These activities may also affect coastal regions, and include shipping (including fishing vessels) and the offshore oil and gas industry. For example, until the 1970s when the offshore oil and gas industry began to develop, the main sources of inputs to the offshore Subregions 1, 2a, 2b, 7a, and 7b, excluding the atmosphere, were commercial shipping and the fishing industry. Of these subregions, 7b is particularly affected by shipping routes (which also, of course, have a major impact on Subregions 4 and 9) but, as the 'Braer' accident in early 1993 dramatically illustrated, frequency of traffic is not the only indicator of pollution risk. Aerial surveys and surveys of beach litter clearly show that ship-generated garbage and waste oil from bilges or tank washings continue to be discharged, despite the provisions of MARPOL 73/78 that make such disposal illegal in the North Sea.

The only point sources in Subregion 2a are the oil terminals at Sullom Voe and Flotta. However, their inputs are regularly monitored and cause adverse effects that are locally detectable. Parts of Subregions 1, 2b, 7a, and 7b are affected by oil, oil/gas, and gas production platforms. These lead locally to the introduction of oil via flaring operations, discharge of production water (i.e., the water separated from the produced oil, condensate, or gas) and, particularly, through the discharge of oil-contaminated drill cuttings.

Apart from the input of oil it is known that the offshore oil and gas industry uses a wide range of chemicals (see Tables 3·17 and 3·18). In 1991, for example, a total discharge of about 1300 tonnes of biocides and corrosion inhibitors was reported to the Paris Commission. The use of such chemicals is at present subject to only minimal control, and little information is available on the extent to which they are detectable in the water column away from the platforms. On the other hand, there is a wealth of information on the effects of oil in sediments around platforms. The fact that releases, even of chemicals supposedly in enclosed use only, do occur is illustrated by the detection of PCBs a) in sediments downstream of Piper 'A', and b) in the vicinity of several platforms. A better understanding of the potential effects and possibilities for control of discharges is already under way through the work of the Paris Commission.

6.5. Contaminant transport – physical

The majority of contaminants entering the sea, regardless of source, do not remain dissolved in the water but become adsorbed onto particulate material and at some stage sediment out. Consequently, movement of most contaminants from the source of input is a complex process and is only loosely related to major water movement patterns. Thus computer models and field data show that inputs from coastal areas of the United Kingdom and France in Subregions 3b and 9 rapidly decline in detectability as they undergo dilution and deposition, and their impact on water concentrations in Subregions 4 and 5 is therefore minimal. In Subregion 4 the natural pattern of water movement generally inhibits the transport of river discharges offshore and keeps them close to the coast. Much of the suspended particulate load is then deposited in the Wadden Sea (Subregion 10) and the German Bight, where it mixes with the input from the Elbe and is moved up the Danish coast in Subregion 5.

The comprehensive data sets of the ZISCH Project (German investigation of circulation and contaminant fluxes in the North Sea, 1986–1987) showed that although regions are affected differently, atmospheric and water transport mechanisms lead to the widespread distribution of nutrients, metals, and halogenated hydrocarbons. Water circulation may transport – via counter-clockwise circulation – inputs from coastal areas of the United Kingdom, Belgium, the Netherlands, and Germany to those of Norway, Denmark, and Germany, including the biologically important Wadden Sea.

Contaminants adsorbed onto fine particulates are progressively transported to areas of deposition. They may be trapped temporarily (from decades to centuries) within estuaries, coastal waters, and areas like the Dogger Bank (see Figure 2·18), for example, or more permanently in deeper seabed depressions, inside fjords trapped by sills, or in areas such as the Skagerrak and the Norwegian Trench that function as sediment traps for the North Sea. This is reflected in the distribution of contaminants, including trace metals and persistent organic compounds, attached to particles in bottom sediments. There is some evidence of elevated concentrations of metals in the fine fraction of sediments examined from the Dogger Bank. The source of these contaminants is not known and needs further investigation. The rate at which this transport occurs is uncertain, but the assessment report for Subregion 8 suggests that 50 to 70% of the particulate load of the North Sea is deposited in the deep water of the Skagerrak, with much of the remainder ending up in the Norwegian Trench.

6.6. Contaminant transport – biological

There is little information available on the extent to which biological processes affect contaminant transport. Benthic animals are known to mobilize some sediment-borne contaminants, but they also contribute to the long-term incorporation of contaminants by transporting them from the surface to the deeper sediment layers.

Some contaminants, as, for example, certain metals and chlorinated substances such as DDT and PCBs, are concentrated in the tissues of marine organisms. Plankton, for example, can incorporate contaminants via biological processes. However, the structure of plankton communities and, thus, the efficiency of energy transfer (and contaminant transport) within the food chain, vary both temporally and spatially within the North Sea. Accordingly, it is not possible to make general predictions regarding the extent to which various contaminants will be incorporated into different types of organisms, and at which levels, in the food chain. In addition, since eutrophication can alter plankton community structure and energy flow, it can also affect the biological pathways of contaminant transport, and there can be synergistic interactions between contamination and eutrophication.

6.7. Contaminant concentrations, inputs, and effects

The presence of a very wide range of chemicals, some natural and some synthetic, is detectable in the marine environment. Assessing the significance of the detected concentrations presents a challenge.

One approach involves comparing the detected concentration with the background concentration, i.e., that which would be found in the absence of any human activity. For a non-natural organic chemical, the background concentration is zero. Many organic compounds, however, also occur naturally, and for such substances and elements the level is probably slowly increasing and certainly will vary according to the proximity of natural land-based inputs. Thus for a number of reasons it is difficult to establish single background concentrations that are applicable to the entire North Sea. The fact that good quality data do not exist for most substances prior to about 1970 increases the difficulty of assessing the relative impact of man's activities. The best method is based on the use of sediment cores, but this procedure can only be carried out in stable deposition areas, and so far only a few such analyses have been made.

A second approach compares environmental concentrations with concentrations derived from ecotoxicological studies. However, most laboratory tests involve the addition of pure chemicals, whereas in the environment, chemicals are often present in complexed or some other less biologically available form. Consequently there are only a few contaminants for which concentration limits have been agreed, based on concern for the ecosystem. The position regarding limits on contaminant concentrations in commercially exploited fish and shellfish to protect human health is further advanced, but even here some caution is necessary because consumption patterns differ, so different limits are set by different countries.

A third approach makes use of biological indicators of exposure to the overall extent of contamination (prevalence of fish diseases, changes in the functioning of enzyme systems, etc.). This provides information on the bioavailability of contaminants and the integration of the effects of multiple exposures over time. However, the interpretation of results based on such indicators is complicated by the spatial, temporal, and biological variations that have natural or as yet unknown causes.

Given these difficulties, in most instances the best that can be achieved at present is to make comparisons of concentrations between areas. Where concentrations are markedly higher than elsewhere they are considered likely to be associated with particular sources that merit closer examination.

Nutrients and eutrophication

Inputs

The inflow of Atlantic water represents the major source of inputs of nutrients to the North Sea, with an estimated annual amount of 4–7 million tonnes of nitrogen (nitrate). In 1990, riverine and direct discharges contributed an additional input of about 0.9 million tonnes of nitrogen, 75% of which entered the coastal zone of the southern North Sea via the Rhine and Elbe rivers as the two largest point sources (Table 6·1). Atmospheric input is the third major source of nitrogen, with an estimated annual input of 0.3–0.6 million tonnes. In the central part of the North Sea aerial transport is more important than fluvial transport, and the inputs of ammonia and nitrogen oxides are higher than previous estimates.

Nutrient inputs via freshwater runoff and atmospheric deposition are to a great extent the result of human activities, but they may fluctuate interannu-

Table 6·1. Annual input of nitrogen through estuaries into selected NSTF subregions.

Subregion	Volume km^3	Seawater flow $10^6 \times m^3/s$	Nitrogen input* 10^3 t	Scaled nitrogen input µmol/l	
				Per volume	Per flow
3a	2 800	0.15*	85	2.2	1.3
3b	1 600	0.15*	80	3.6	1.2
4	1 300	0.16	380	20.9	5.4
5	700	0.18	215	21.9	2.7
6	16 000	1	30	0.1	0.1
8 (Kattegat)	500	0.06	70	10	2.6
8 (Skagerrak)	7 300	1	30	0.1	0.1

Source: ICES, except *, based on the averaged results from a number of models.

ally owing to natural variation in precipitation. The run-off also has marked seasonality; for example, the input of nitrogen from the Rhine and the Elbe is greatest during winter and spring. This nitrogen originates from agriculture, sewage, and industrial discharges, as well as natural sources. The concentrations of nitrate in the major rivers that discharge into the southern North Sea (Elbe, Rhine, Meuse, Scheldt, Thames, and Humber) are about 50 times higher than the background concentration in Atlantic water. An important source of nitrogen for primary production is internal recycling within the water column. This mechanism appears to work at varying levels of efficiency in different areas of the southern North Sea. Nutrient recycling may thus act as a buffer in the sea to the reduction of nutrient inputs.

For phosphate the annual input by Atlantic water is approximately 800 000 tonnes. The input by rivers and direct discharges in 1990 was estimated to be about 45 000 tonnes, of which the largest fraction came from sewage and urban sources. The atmosphere is not a major source of inputs of phosphate.

Trends in inputs

The input of phosphate via the Rhine and Meuse increased by a factor of 7 to 10 between 1930 and 1985, and the input of nitrate increased by a factor of about 4. Between 1985 and 1990 a clear reduction in phosphate input of 30 to 40% took place, whereas the decrease in the nitrogen input during this period was less pronounced and of doubtful significance. With the exception of the Seine, where a 4% decrease in the load of dissolved phosphate was observed between 1983 and 1991, information of comparable quality was not available for major rivers.

Phosphorus and nitrogen loads from the Elbe have declined substantially since 1987, but whether this is attributable to reduced inputs or to the reduced flows of 1989 and 1990 is not known.

The third important nutrient for the growth of some phytoplankton is silicate. Inputs of silicate via rivers have not increased in recent decades. Silicate is necessary for the growth of diatoms, and is normally the first nutrient to become depleted during the spring bloom. The remaining surplus of nitrogen and phosphate is then available for those species that do not require silicate for growth, e.g., flagellates such as *Phaeocystis* spp.

Concentrations

Monitoring results show marked elevations of nitrogen concentrations in the North Sea out to a salinity of 33. At this salinity the river water has been diluted 18 times, but in most coastal areas the winter concentration of nitrogen is still at least twice as high as the concentration in Atlantic waters. High concentrations are found in coastal areas from northern France to Denmark, with somewhat lower levels prevailing along the southeastern coast of England (Figure 3·17). Elevated concentrations, originating from the southern North Sea, have regularly been found in the upper or intermediate layers of the eastern Skagerrak and, on occasion, in the Kattegat as well.

The winter distribution of phosphate shows the same pattern as nitrate, with elevated concentrations in the coastal areas of the southern North Sea.

Trends in concentrations

Winter phosphate concentrations increased substantially (by a factor of 3 to 4 in some areas) in the coastal strip of the southern and eastern North Sea over the period from 1935 to 1990 (Figure 3·19). The area affected by a doubling or more represents about 10% of the total area of the North Sea.

In the inner German Bight at Helgoland a marked increase in nitrogen has been observed since the late 1970s, both in winter and summer. Phosphate increased until the late 1970s and decreased during the 1980s. The decrease in phosphate is assumed to reflect the efforts made to reduce its use and to treat sewage.

Measurements of nitrate and phosphate along the east coast of the United Kingdom and of phosphate in the Southern Bight have not indicated any significant changes for several decades.

Nutrient ratios

The normal N/P consumption ratio for marine phytoplankton is 16:1, and under normal circumstances nitrogen is the limiting nutrient in the marine environment. The observed and calculated ratios in river inputs (phosphorus is usually regarded as the limiting nutrient in fresh water) have been as high as 40–60:1. This surplus of nitrogen leads to a condition in which phosphorus limitation of phytoplankton photosynthesis now occurs in spring/early summer in the continental coastal regions where nitrogen was previously considered to be the limiting nutrient. The excess nitrogen in these areas is advected to other regions where it increases the total available nitrogen and changes the N/P ratio. A change in the N/P ratio has an effect on phytoplankton species composition and may stimulate toxin production in some species. Laboratory studies suggest, for example, that the high *in situ* N/P ratio may have increased the toxicity of *Chrysochromulina polylepis* in the Skagerrak and Kattegat in 1988. An elevated N/P ratio is now often observed in winter from the southeastern coast of the United Kingdom to the area north of Denmark (Figure 3.21).

Effects

The increased input of nutrients combined with the resulting change in nutrient ratios has altered phytoplankton community structure and succession in some regions of the North Sea. These alterations have led to changed patterns in the flow of energy in the food chain, as evidenced by increased production and biomass of phytoplankton, changes in planktonic species composition including the occurrence of harmful algae, changes in benthic algae and animal communities, and increased consumption of oxygen in water and sediment, leading to reduced concentrations of oxygen and thereby mass mortalities of benthic organisms and fish.

The effects are observed in the nearshore and coastal waters along the east coast of the North Sea. Along the Dutch coast in the Wadden Sea and in the German Bight, the increased production has been clearly documented. The best examples of changes in phytoplankton species are the increased duration of the *Phaeocystis* spp. bloom in the Marsdiep (westernmost Wadden Sea inlet) over the last three decades, and the increase in the ratio of flagellate/diatom biomass in the German Bight since the mid-1970s. The bloom of *Chrysochromulina polylepis* in 1988 in the Skagerrak and Kattegat may have been caused by a combination of high levels of nitrate, a high N/P ratio, and unusual meteorological conditions. An imbalance in nutrient availability could underlie the toxicity of this bloom, since laboratory results have shown an increase in cell toxicity under phosphorus stress.

In Dutch coastal waters and the German Bight, changes have been reported in the population of zooplankton, such as, for example, higher numbers of small copepods. Increased biomass and changes in the species composition of zoobenthos have been observed in the Wadden Sea and the German Bight, on the northern Dogger Bank, and in the Kattegat and eastern Skagerrak. Effects on the growth of macrophytes have been observed in the Wadden Sea, at localized sites in some United Kingdom estuaries, in Danish inlets and the Kattegat, and along the Swedish west coast and in the outer Oslofjord. Areas with reduced oxygen concentrations have been documented in the southeastern North Sea, the Wadden Sea, west of Denmark, in the Kattegat, and in Swedish and Norwegian fjords. In some of these fjords oxygen depletion has been observed for decades and is correlated with restricted water circulation and not eutrophication. Consumption of oxygen in Kattegat deep water increased in the 1980s, and 50–100% oxygen depletion was commonly detected when the water column was stratified.

In offshore areas of the North Sea with high-salinity water there are no clear signs of eutrophication effects in the water column. Changes in plankton composition have been observed since 1930, but they are thought to be related to changing climate patterns. Increased production in coastal waters may, however, lead to an increase in food availability for offshore benthic communities. It has been suggested that the increased biomass and changes in benthic community structure on the Dogger Bank may be linked with increased inputs of nutrients, although other causes such as effects from fisheries and natural variability could be responsible.

Trace organic contaminants

Inputs

A great many persistent organic substances are introduced into the North Sea through atmospheric fallout, riverine inputs, leakages from waste sites along the coasts, and Atlantic and Baltic waters. It is not possible to quantify these inputs with precision, owing to a lack of adequate data even for well-studied substances such as PCBs and DDT. The importance of atmospheric transport is well illustrated by the data on the insecticide lindane (γ-HCH).

Concentrations

Persistent organic compounds have been found all over the North Sea in water, sediments, and animals, indicating that the whole area is contaminated, but the levels observed vary with distance from the source (site of input or sedimentation area for the contaminants) and with the species analysed.

The highest concentrations reported are normally found in estuaries and coastal areas from the east coast of England and the Channel to the German Bight, and in the Kattegat and Skagerrak, and in some Norwegian fjords. For some organic contaminants, elevated concentrations have also been reported from more offshore areas, as, for example, the northeast Dogger Bank and around some oil platforms in the central North Sea.

Effects

Many of the trace organic contaminants entering the North Sea are very slowly degraded (if degraded at all) and bioaccumulate and biomagnify in marine food chains. Their ubiquitous occurrence and global distribution are well known. The highest concentrations of these compounds are found in marine biota, particularly in top predators. Most of these contaminants are man-made and should not be present in marine organisms at all.

The availability of data on their biological effects and environmental significance is unfortunately still very limited. However, several negative effects on animals have been observed, e.g., decreased reproductive success, increased susceptibility to disease, and lower survival rates. Studies on seals from the Baltic Sea and the Wadden Sea have shown a clear correlation between the concentrations of PCBs in fish eaten by the seals and reproductive failure.

When discussing biological effects one should be aware of the limitations often set by the approaches selected in the great majority of investigations where a few toxicants are tested and correlated with effects. At high concentrations these contaminants are acutely toxic to most species, but owing to their low water solubility and resistance to degradation, damage caused by low-level exposure or by constantly increasing concentrations in lipid structures (bioaccumulation) is considered to be the main risk in nature. In field studies a fundamental problem is how to ascribe the observed effects to specific compounds, because they tend to be present together in complex mixtures.

Many organic contaminants affect the biotransformation systems, such as cytochrome P-450, in marine organisms. The resulting elevated levels of the biotransformation enzymes can be regarded as a compensatory defence mechanism, and may not necessarily lead to detectable consequences for the organism. However, these enzymes are also involved in critical physiological processes such as steroid hormone synthesis/inactivation and fatty acid metabolism.

Several studies of fish that inhabit contaminated waters have revealed an increased prevalence of tumours, particularly in the liver. Although tumours can occur naturally, exposure to sediment-associated chemical contaminants, especially PAHs, is suspected of being the main cause.

In addition to the concern over the possible effects that organic contaminants may have on marine species, the higher concentrations found, as in the liver of certain fish species from certain areas, have led to precautionary controls being imposed on the consumption of particular species and tissues.

Thus for a variety of reasons it is important that efforts continue to be made to reduce inputs of persistent organic contaminants and to strengthen existing measures to control or destroy PCBs more effectively than at present.

Lindane (γ-Hexachlorocyclohexane, γ-HCH)

The highest concentrations of lindane in water are found in certain estuaries, probably reflecting the agricultural use of this product, such as in the Elbe and Humber estuaries (up to 15 ng/l) and along the southeastern coast of the North Sea; a seasonal variation of the input has been observed in the Western Scheldt. The lowest values reported are from the central North Sea and the Channel (generally 1 ng/l).

Given its moderate solubility in water, concentrations of lindane in sediments from the Skagerrak, Kattegat, and Norwegian Trench were, as expected, reported to be very low. In fish liver the highest reported concentrations were found in whiting in the outer Thames Estuary, the Wash, and the Southern Bight (27–37 μg/kg). Relatively high concentrations were also reported in dab, cod, and plaice from the western Channel and the west coast of Norway.

In mussels the highest values were reported from the northwestern German coast (East Friesland), while uniformly low values were observed along the west coast of Norway. These results may reflect the higher concentrations of lindane in coastal waters of the Netherlands and Germany than in those off southwestern Norway.

As seen in Table 3·6, Norwegian rivers are among the sources of highest input of lindane to the North Sea. Although the actual concentrations in the rivers are low (typically 0.5 to 5 ng/l), the total input is high owing to the heavy run-off of fresh water. Lindane was used in forestry in Norway in the 1970s and early 1980s, but its use was reduced to 370 kg by 1990 and fell to only 39 kg in 1991. Thus, the figures may reflect the run-off of long-range transported contamints in the precipitation over Norway.

Monitoring in the German Bight between 1980 and 1991 indicates a reduction in α-HCH in the water as a result of the ban on the use of technical HCH, while there are no trends regarding γ-HCH. In plaice from the outer German Bight and in flounder as well as water from the Elbe Estuary, a downward trend was observed between 1988 and 1991, following reductions in inputs to the Elbe. In mussels a downward trend has been reported for both the German Bight and the Baie de Seine.

Polychlorinated biphenyls (PCBs)

The highest values of seven chlorinated biphenyl congeners (7CBs) in sea water have been reported from coastal waters, and in 1986–1988 concentrations up to 178 pg/l were detected in the German Bight, 33 pg/l off Scotland, and 16–29 pg/l along the coast from France to the Netherlands. The values normally observed in Atlantic waters are between 3 and 12 pg/l. However, elevated concentrations of total PCBs were also observed in a transect through the Argyll, Auk, Fulmar, and Ekofisk oil fields, which presumably reflected recent illegal discharges of the product Aroclor 1254 (a PCB product) since the formulation pattern very closely matched that found in the environment.

In 1990–1991, the highest levels of total PCBs and selected CB congeners in sediments were reported along the coasts of France, Belgium, the Netherlands, and Germany, in the Skagerrak and Kattegat, and in the inner Oslofjord. The values initially reported by the United Kingdom were all lower than their reporting limit of 2 µg/kg. Subsequently, when lower reporting limits were used, the highest concentration reported by the United Kingdom was 0.06 µg/kg. The high values of PCBs observed in the sediments of the Skagerrak and Kattegat reflect the long-range transport and fallout of PCBs from the atmosphere, and the sedimentation of particle-bound PCBs transported by water currents from sources farther south in the North Sea and from the Baltic Sea.

The highest values of PCBs in sediments and fish reported from Norway are from harbour areas such as Oslo and Bergen (close to a naval base). These observations probably reflect run-off and leakage from earlier activities and poor waste handling. Similar situations can be expected in many other civil and naval ports around the North Sea. The data reported to the Oslo Commission on PCBs in dredged material, although not complete, tend to confirm this.

The levels of PCBs in fish vary with distance from the source and also with the fat content of the exposed fish. Dab, which have a low fat content, normally have much lower concentrations than do whiting, which have a high fat content. Analyses of a single fish species such as dab would therefore tend to give a more optimistic picture than those based on whiting. If data were available for even one common species caught throughout the entire North Sea, it would be easier to give a more complete picture. However, the available data do indicate areas with high or low inputs and where accumulation may occur in sediments and organisms.

For dab, cod, and flounder the highest concentrations of 7CBs in liver tissue (up to 1.3 mg/kg) have been found in the Southern Bight, Western Scheldt, and Oslofjord and in some fjords on the west coast of Norway. The highest levels of total PCBs in liver are, however, reported from whiting caught in the southern North Sea, off the Thames Estuary, and in the Channel (mean values of up to 2–6 mg/kg).

For PCBs in fish liver there is a clear gradient in concentrations from low values in the northern North Sea to high values in the southern North Sea and the Channel (Figure 3·7). This reflects a higher input by the rivers and/or large point sources somewhere in the Channel, probably close to, or on, the French coast.

In mussels the highest values of 7CBs are reported from the estuaries of the Western Scheldt and Ems and from the Wadden Sea. The highest concentrations of total PCBs are reported from the Thames Estuary, the Baie de Seine, and along the coasts of France and Belgium.

Although there has been a ban on new uses of PCBs in most European countries, high concentrations are still found in both sediments and fish liver. However, a decreasing trend seems to have occurred over the past decade for several species and geographical areas. For total PCBs a slowly decreasing trend was observed in cod liver from the Dutch coast between 1979 and 1991; however, no such trend could be observed in dab. For CB153 a downward trend has been observed in flounder from the outer and inner German Bight.

For whiting in the southern North Sea and the Channel a trend has also been observed over the last decade, decreasing from values as high as 25 mg/kg to 2–5 mg/kg in fish liver. Although whiting liver is not eaten, it should be noted that the levels exceed the national limits set for human consumption in Scandinavia. In the Oslofjord, a decreasing trend was observed between 1985 and 1990 in both fish liver and mussels, but since 1990 the values have fluctuated.

Hexachlorobenzene (HCB)

In sediments the highest values are reported from the Elbe, Ems, and Weser estuaries, the German Bight, the Skagerrak, and Oslo Harbour. In the Firth of Forth, elevated concentrations of several chlorobenzene compounds from a local source were detected. The concentrations decreased by a factor of 10 to 20 between 1987 and 1990 in response to input reductions.

Dieldrin

Most of the data on dieldrin were supplied by the United Kingdom, where the highest concentrations of this compound (up to 170 µg/kg) in fish liver (cod and whiting) were reported from the east coast of England (Humber and Thames estuaries and the Wash) and the Channel.

Data on mussels are available for only a few sites; they show low concentration values (below 2 µg/kg wet weight).

DDT

The highest concentrations of total DDTs have been reported from fish and mussels in the Hardangerfjord/Sørfjord, Norway. High concentrations were also reported for cod from the Kattegat and for whiting from the Thames Estuary and the Channel. For mussels the highest values reported were from the Channel, Sørfjord, and the Western Scheldt. The observed values indicate that DDT may still be used in some areas, but other possible sources are leakage from old waste sites and sites of previous heavy use such as fruit farming, as well as long-range atmospheric transport and fallout over the North Sea and adjacent countries.

Tributyl tin (TBT)

A sensitive indicator of the toxicity of TBT to marine organisms is its effect on dogwhelks, which occurs at concentrations below those known to affect other marine organisms. Surveys carried out as part of an NSTF programme have shown effects due to TBT, manifested as imposex (occurrence of male sexual characteristics in females) in the dogwhelk, in harbours and along the North Sea coastline from the Channel to western Norway and Scotland. Historical records show that dogwhelks have disappeared from several areas, including the Southern

Bight, over the last decade. In shipping areas in the southern North Sea, similar effects observed in dogwhelks are probably due to the release of TBT from ships. There are no dogwhelks at all in the very busy coastal shipping lanes of the southern North Sea, but a high incidence of penis homologues (a manifestation of imposex) was observed in dogwhelks from the offshore deepwater shipping lane, and a low incidence at the stations near the Dogger Bank.

In estuaries close to marinas in the United Kingdom a marked decrease in TBT concentrations has been observed, while concentrations in some harbour and dock areas remain high and variable. These findings indicate that the effects due to TBT are more serious than previously expected. However, in places where a ban on the use of TBT-paints on yachts measuring less than 25 m has been imposed and enforced, concentrations have decreased and ecological recovery is clearly apparent.

Polycyclic aromatic hydrocarbons (PAHs)

Owing to a lack of input data it is difficult to assess the relative importance of different sources of PAHs. Studies of sea water on a transect across the Strait of Dover (Fluxmanche project) indicate that some derive from shipping. Analyses conducted around oil platforms also reveal a clear input from drilling (cuttings) and production (flaring). Aluminium and smelting plants situated in the inner part of some Norwegian fjords are examples of important local sources. In addition to natural sources, there is a major contribution from the burning of fossil fuels, e.g., emissions from cars and planes, energy production, and other industrial activities.

The highest values of different PAHs in sediments have been reported from some estuaries, including the Scheldt, and some fjords in Sweden and Norway. However, high values have also been reported from the Dogger Bank, the Skagerrak and Kattegat, and the Norwegian Trench. These results indicate that long-range transport of PAHs and the transport and deposition of fine sediments play an important role in the distribution of PAHs in sediments.

An increased frequency of fish liver tumours, reduced scope for growth in mussels, and induction of the EROD enzyme in flatfish liver, have been attributed to elevated levels of PAHs in some North Sea sediments.

Metals

Inputs

The distribution of dissolved trace metals in the North Sea is the result of inputs from coastal and riverine sources (some of which are natural), sediments, and the atmosphere, and of a complex of interacting physical, chemical, and biological processes. Table 3·2 clearly shows that concentrations of dissolved metals in the offshore regions of the Channel and North Sea are generally not more than double the concentrations typically found in open Atlantic waters. In the Kattegat and Skagerrak, concentrations are up to ten times higher than in the Atlantic, but this probably reflects in part the lower salinity of the waters in that area, i.e., the increased influence of river run-off. The influence of river inputs is also particularly apparent in the major river estuaries around the southern North Sea.

Because of changes in methods it is difficult to make sensible comparisons with historical data or even the data reported in the 1987 *QSR*. In most areas it is apparent that inputs have decreased rather than increased, but in only a few areas can decreases be detected for dissolved metal concentrations, e.g., in cadmium off the Rhine. This is mainly due to the fact that most of the other metals adsorb onto particulate matter in the water column. The effect of input reductions will therefore become apparent in sediments but in most areas only slowly because the surface layers of sediments are frequently disturbed by trawling, wave and storm action, and bioturbation.

Concentrations

The distribution of metals in sediments depends on a variety of geological factors, including the source of origin of the material and the proportions of fine and organic matter. A major spatial survey of metals in total sediment was undertaken at the instigation of the Joint Monitoring Group (JMG) of the Oslo and Paris Commissions and was supported by the NSTF. Particularly good coverage was achieved by Norway in its coastal and fjord regions and by the United Kingdom in the English sector of the North Sea and the Channel. Less complete coverage was achieved elsewhere, which means that the majority of identifiable higher concentration areas are in Norwegian or United Kingdom sectors. The estuaries of the Tyne, Tees, and Wear, along the east coast of England, which drain mineralized catchment areas and receive inputs of metals from industrial sources, and a number of Norwegian fjords, e.g., Sørfjord and Hardangerfjord on which metal-ore processing plants are situated, are identified as areas in which metal concentrations are clearly elevated. Concentrations in fjords have decreased since 1985. Sediments in the Humber and Thames estuaries were similarly relatively more contaminated than those offshore. Few comparable data were available for the coastal area affected by the Rhine or the Elbe. Fine fraction data for these areas do, however, suggest that they are affected by concentrations of metals that are relatively high. Offshore regions were generally found to be only slightly contaminated, the exceptions being those known or suspected to be deposition areas. Thus, for example, concentrations of lead, which is largely transported via the atmosphere, were found to be clearly elevated off the northeast coast of England, in the Tail End region of the Dogger Bank, and in the Norwegian Trench, which showed clear evidence, from analysis of a core sample, of increased lead deposition starting about 200 years ago.

Most of the data reported on temporal trends in metal concentrations relate to biota. Only some of the data are suitable for accurate assessment of trends, but the picture is generally encouraging, with most of the downward trends noted in the 1987 *QSR* continuing. There are, however, a number of exceptions. For example, in the Oslofjord, data for cod and flounder show an upward trend for mercury as do the data for herring and dab (though not cod) from the Kattegat. In the outer Seine, cadmium concentrations in mussels seem to be increasing as are concentrations of lead in flounder from the Baie de Seine. In the estuary of the Elbe, concentrations of cadmium and mercury in mussels are relatively stable; however, zinc concentrations in mussels and lead in the liver of flounder showed an increasing trend during the period 1985 to 1989. Concentrations of cadmium, chromium, copper, and zinc in sediment from the central Dutch coastal waters significantly decreased between 1981 and 1991.

Effects

Little is known about the ecological significance of metal concentrations in marine fish and shellfish. Concern has been expressed, however, about the potential effects of high concentrations of lead, cadmium, and mercury in relation to top predators such as seals and certain seabirds. With the exception of flounder and eel in the Elbe and its estuary (which are not allowed to be sold because of their high mercury content), none of the concentrations of metals found in commercially exploited fish or shellfish in any of the areas of the North Sea exceed standards set to protect human health. There are also some instances where concentrations in mussels, e.g., from the Tyne and the Sørfjord in Norway, have exceeded standards set by other national authorities, although neither stock of mussels is used as food for human consumption, but exclusively as biological indicators.

Thus, while there continue to be good reasons for exercising control over metal inputs in general, if present controls and decreases in inputs are maintained, the desired improvements should be achieved in most areas. Points that remain to be clarified are the biological significance of the highest concentrations of metals in both total and fine fractions of sediments and the speed of recovery in areas of short- to medium-term deposition.

Petroleum hydrocarbons

No recent estimate has been produced of the magnitude of oil inputs from all sources to the North Sea. Table 3·19 is based on that in the 1987 *QSR*, but now includes an estimate of non-operational inputs from shipping. Although the reliability of these estimates is generally poor, the ranges are probably representative and sufficient to show the relative proportions which each source represents. As noted in 'Other sources' (p. 102) the major source of oil inputs from the activities of the offshore oil and gas industry is the disposal of cuttings arising from the use of oil-based muds.

Production water is expected to make an increasingly greater contribution to the total input of oil as fields reach maturity and approach the end of reserves. This is especially so because improvements in cuttings cleaning technology and the types of oils used have led to substantial reductions in this source of input over the last five years. The disposal of oiled drill cuttings at the site of drilling has now virtually ceased in the Norwegian sector, and only the United Kingdom still permits the disposal of such cuttings on site (due to cease in 1994 for exploration wells and in 1997 for all wells, in accordance with the Paris Commission guidelines). Nevertheless it has been estimated that up to 2% of the seabed of the total North Sea has been affected by oiled drill cuttings, i.e., oil is detectable in the sediments and/or there have been changes in the species present. Monitoring of the piles of contaminated cuttings around some of the worst affected platforms shows effects on zoobenthos within 0.5 to 1 km of the platform. Occasionally, there are detectable effects up to 5 km from the installation. At a number of platforms, once drilling has ceased the area in which biological effects or oil contamination are detectable decreases; macrobenthos recovery in the moderately affected zones usually takes place within two to three years. Although inputs of oil on drill cuttings have declined, the decrease has been more or less matched by an increase in oily water discharges arising from the produced water pumped up with oil from the reservoirs. The concentration of oil in these oil/water discharges is limited by PARCOM regulations to less than 40 ppm and is not expected to have any toxicological effects. However, there are reports of oil being detectable in the tissues of fish well away from oil production platforms, and this has been identified as stemming from oiled drill cuttings.

Of greater concern, if for no other reason than that the effects are more obvious, are the quantities of oil entering the sea from ships as illegal discharges and from incomplete gas flaring operations on oil platforms. These give rise to surface films that can lead to the oiling of seabirds and the death of birds so affected. The assessment report for Subregion 4 suggests that as many as 40 000 birds die each year on the Dutch coast alone as the result of oil contamination, much of it arising from illegal discharges from ships. The numbers of oiled birds found on North Sea coastlines have not in general declined. One exception is the German coast where reductions have been noted.

Radionuclides

Man-made radionuclides are clearly detectable in the marine environment against the considerable background of natural radioactivity. Levels of plutonium in the North Sea are very low; in terms of public radiation exposure only caesium-137 is of any real significance. Since 1984 the levels of this radionuclide in the North Sea have declined by a factor of about ten. This is a consequence of reductions in inputs from the Sellafield reprocessing plant in the Irish Sea and decreases in the effect of releases from the Chernobyl accident. The decline in the effect of the Chernobyl accident is less marked in the Kattegat and Skagerrak owing to the influence of the more heavily contaminated Baltic water outflow. The French reprocessing plant at Cap de la Hague leads to clearly detectable increases in radionuclide concentrations in coastal waters along the eastern North Sea.

In no case do the concentrations of these artificial radionuclides give rise to concern about the health of human populations. In fact, human exposure to radiation from artificial radionuclides is less, by two orders of magnitude, than that from natural radionuclides.

Natural radionuclide inputs are usually widely dispersed, and elevated concentrations arising as a direct result of anthropogenic activity are rare. One exception was noted in the assessment report for Subregion 4 in which the phosphogypsum industry on the Dutch coast is seen to represent a major point source of polonium-210.

This is a relatively new concern and needs to be investigated, not just in coastal waters off the Netherlands, but also in other areas where phosphogypsum discharges occur or have occurred in the past, as off the coast of France in the Baie de Seine. With this exception, the cause for concern over discharges of radionuclides appears to be decreasing and, provided that the expected further reductions in inputs occur with the introduction of new treatment facilities now being installed, this pattern of decreased exposure and reduced cause for concern ought to continue.

6.8. Conclusions

The health of the North Sea

1 In terms of physical oceanography, the North Sea can be considered as a unit, but its great heterogeneity becomes apparent in any assessment of its health. Large areas can be shown to be subject to concentrations of contaminants that are clearly above the North Atlantic background level. Generally, the impact of these enhanced concentrations, which are directly attributable to inputs from around the North Sea, is only clearly identifiable where the concentrations are highest, that is, close to the sources, e.g., in estuaries or in deposition areas such as the Norwegian Trench and parts of the Dogger Bank, or in the Wadden Sea and sea areas where the pattern of water movements restricts water exchange, e.g., along the Dutch and Danish coasts.

2 Some detectable effects can be attributed to particular contaminants, as, for example, the effect of high concentrations of PCBs on the reproductive success of seals and the effect of TBT on the shell shape of oysters or the induction of imposex in dogwhelks. Where the cause of an effect is not clearly identifiable two possibilities must be considered, namely some hitherto unidentified contaminant and/or several substances which are acting together. The fact that only a few persistent organic contaminants have received any attention at all is a major cause for concern and uncertainty.

3 Apart from some local effects of the offshore oil and gas industry, there are few serious problems in the northern or central parts of the North Sea. Effects become increasingly more readily identifiable from west to east up the Channel, from north to south in the North Sea, and as one approaches the coastal margins and estuaries.

4 Along the coastal margins, particularly of the Southern Bight and German Bight, the development of agriculture, industry, and tourism imposes severe pressure on the habitats for species that require intertidal, saltmarsh, or other forms of coastal habitat, and in some cases breeding, feeding, or resting sites have been almost completely eliminated.

5 Estuaries and other sheltered areas such as the Wadden Sea are important as nursery grounds for young fish and as feeding grounds for seabirds. These same areas are also those most likely to be affected by the highest inputs and concentrations of contaminants.

6 The populations of animals that live on the seabed (benthos) are subject to a variety of pressures from dumping (mainly physical covering), dredging (either for harbour maintenance purposes or for sand/gravel extraction), the discharge of drill cuttings (oiled or otherwise) from offshore platforms, the frequent passage of heavy trawl gear, and reduced oxygen levels associated with collapsing algal blooms. The short regeneration times of most of the species affected means that the populations are capable of fairly rapid recovery when the cause of impact is removed. Longer-lived species recover less readily, and even where the pressure is not great, species shifts in the natural ecosystem are likely. Where the pressure is intense, more severe changes will occur and sizeable areas may be affected: more than 1000 km^2 in total, e.g., for the areas affected by oiled cuttings or by heavy trawl gear.

7 Higher winter nutrient concentrations than in the central North Sea are found along the southeastern coast of the United Kingdom, with more strongly elevated concentrations along the southern and eastern coasts from northern France to Denmark and elevated concentrations in the Kattegat and eastern Skagerrak. There is a high content of nitrogen in the riverine and direct discharges which is reflected in high levels of nitrate and elevated N/P ratios in the coastal waters during winter and spring. Eutrophication effects are seen in some coastal regions of the Southern Bight, the German Bight, the Kattegat, the eastern Skagerrak, some areas of the French Channel coast, and two small United Kingdom estuaries.

8 Fish stocks in the North Sea have been altered by centuries of fishing. The introduction of modern fishing methods and equipment has increased the potential, and in many cases the actual, impact on the system. Population age structures of many demersal fish species now consist mainly of relatively young fish. Most commercial species can be expected to produce higher yields if the level of fishing effort is reduced. There are some species which are at present exploited at levels that are considered to be in excess of sustainable levels, and fishing effort on these stocks urgently needs to be reduced.

9 It is clearly recognized that fishing results in the by-catch mortality of a wide range of non-commercially exploited fish species. The impact of this source of mortality on the populations of those species is generally not known. Certain types of fishing gear also cause the death, through entanglement and drowning, of marine mammals and diving species of seabirds. The available statistics are too few to be considered representative, and the overall impact on populations cannot be clearly established at present. Fishing has some positive effects on bird populations through provision of extra food as offal and discarded by-catch. It also has the potential to cause negative effects, e.g., by removal of essential food supplies through heavy fishing. If the stock is suffering low recruitment for other more natural reasons, such as weather- or climate-induced current change, this additional stress could be severe.

10 From the above it will be apparent that the causes of identifiable problems are not always obvious. Nevertheless some clear issues of concern can be identified, and certain conclusions are apparent. These are delineated in the final section of this chapter.

Issues of concern

1 In terms of gross input to the North Sea, rivers account for the largest proportion of most contaminant inputs, followed by dredged materials, and atmospheric inputs. The impact of other smaller point sources can, however, be highly significant and should not be ignored. In order to reduce inputs via the atmosphere and dredged materials, reduction of emissions at the source will usually prove to be the most effective method. Distant source control may also be the only way of achieving river input reductions, e.g., in the case of the HCH input from Norwegian rivers. It must also be recognized that for some rivers, such as those in northeast and southwest England, inputs of metals such as lead, zinc, copper, arsenic, and cadmium are largely derived from natural ores.

2 Certain deposition areas in which contaminants are accumulated can be identified. These may be short-term deposition sites, e.g., estuaries; medium-term, e.g., Oyster Grounds, the Wadden Sea, and parts of the Dogger Bank, such as Tail End and Silver Pit; or long-term, e.g., the deeper parts of the Skagerrak and the Norwegian Trench. The availability of contaminants in sediments, possible organic enrichment, and the impact on benthic species composition are uncertain and need to be clarified.

3 There are few internationally agreed environmental objectives or standards. A number of workshops have been organized under the NSTF to try to develop overall ecological objectives and what may constitute background concentrations of natural compounds. This will help in determining the significance of 'high' concentrations and what they mean in terms of the desired ecological quality.

4 Reductions in inputs have been achieved both before and after 1985. These are clearly identifiable in the statistics for point sources and, with somewhat greater uncertainty, for the more aggregated sources such as rivers. This is partly due to the lack of accurate measurements in earlier times and the fact that 1985 was not an equally typical year for the flow of all rivers. The difficulty in achieving reductions is, however, evident in the statistics on river inputs. For example, for the Rhine, there is no evidence of nitrate inputs having been reduced in recent years, and for the Elbe, concentrations of some contaminants have decreased since 1990 but sometimes show sharp peaks. Reductions in environmental concentrations are clearly identifiable in some cases, e.g., biodegradable organic matter and phosphate in the Rhine. In others, owing to historical inputs and accumulation, they will take some years to become apparent; for example, model studies on nutrients predict that a 50% reduction in inputs will initially produce only a 20% change in environmental concentrations, and past burdens of mercury in the sediments of the Elbe and Thames will continue to contribute to the contaminant load of locally resident fish.

5 Concentrations of metals in sediments in certain estuaries, fjords, and coastal waters, e.g., the German Bight and Wadden Sea, are clearly still elevated. Although in some cases reductions are detectable, concern continues to be expressed that no reductions in the metal burden of biota in the Wadden Sea have been detected thus far. There is, however, evidence from a recent examination of sediment data by Dutch scientists that metal levels in sediments off the Dutch coast have begun to show a decrease over the last decade. Thus, despite the residual indications of cause for concern, provided that existing input reduction measures are maintained, improvements ought to become apparent and there should be few instances where metal inputs cause pollution.

6 Only a relatively small number of synthetic organic compounds are identifiable as being present and quantified in the marine environment. Many others probably exist and may or may not cause effects. There is a need to establish methods to trace sources of these substances and their effects in the environment. This will give a better picture of the total threat to the North Sea. Most of those that are identifiable are widespread, e.g., PCBs, HCH, DDT, PAHs, and TBT, although higher concentrations are clearly identifiable in certain areas. For example, higher concentrations of PCBs are found in the southern part of the North Sea and close to harbour and city areas, and TBT concentrations are higher in some estuaries, harbours, and shipping lanes. Such findings indicate that existing levels of destruction and input restrictions for PCBs are only partially effective, and that controls on the use of TBT-based paints and the disposal of paint chippings are not uniformly effective in all countries.

7 Despite reductions detected in some areas, the levels observed for a number of persistent organics in certain fish tissues and sediments remain quite high. The highest concentrations exceed values reported to have effects on marine mammals and birds. The international bans applied to some of these products have not yet achieved the desired reductions in the environment. Mapping and tighter controls of land-based disposal sites close to the shore and more extensive use of proper destruction techniques may be called for.

8 The microbiological quality of molluscan shellfish stocks is adversely affected by inadequately treated and sited sewage discharges. As a consequence there are real human health risks that can only be eliminated either by avoiding the contaminated areas or, where the shellfish are only lightly contaminated, by subjecting them to approved purification techniques.

9 The quality of water in bathing areas can be adversely affected by discharges from inadequately treated sewage as well as from agricultural areas and storm water run-off. There are real differences between subregions with respect to their compliance with Directive 79/169/EEC of the European Economic Community's imperative value for faecal coliforms, but it is unclear whether these variations are explicable in terms of analytical differences. These differences will have to be resolved by proper international intercomparisons and standardization of methods.

10 Elevated nitrogen and phosphorus concentrations and disturbances in the natural balance of N:P:silicate ratios are clearly detectable not only in many estuaries and in the vicinity of river and sewage outfalls, but also along most of the coastline from northern France to Denmark, sections of the southeastern English coast, and in parts of the eastern Skagerrak and the Kattegat. These changes are generally accepted to be a cause of increased phytoplankton biomass and bloom duration though not necessarily the reason for their occurrence. They may also stimulate nuisance blooms of phytoplankton such as *Phaeocystis* spp. Other associated adverse effects include alteration of plankton and benthos community structures and reduced dissolved oxygen levels in the water column as the phytoplankton bloom cells decompose with, in extreme cases, complete anoxia, and kills of the benthos. Such events have occurred in the German Bight and Kattegat in the last decade.

11 The offshore oil and gas industry is a substantial source of petroleum hydrocarbon inputs. Although large quantities of production water are discharged, the concentrations of oil are low, and this source is regarded as being less of a problem than drill cuttings and inefficient flaring operations. Drill cuttings cause contamination of the seabed and detectable effects on the benthos around the platforms. Oil-derived compounds have been identified in fish well away from the platforms and in a few cases have caused oil taint in flatfish. Visible oil slicks may arise from flaring and cause the death of seabirds. The offshore industry also uses a wide range of chemicals, but the quantities discharged are uncertain. Despite claims that, in many cases, the use of chemicals does not lead to significant discharges, the detection of elevated levels of contaminants downcurrent of platforms demonstrates that this is not the case.

12 Shipping continues to be the main source of oil slicks that are frequently reported on the sea surface. There has been no decrease in the number of oil slicks observed, and most of them stem from illegal discharges. In general no clear trend in the oiling rate of beached birds has been registered over the last 20 years, although in some local areas, e.g., at the Shetland and Orkney Islands and along the German coast, a decline has been observed. With respect to the decline along the German coast, it is under discussion whether this is an effect of the free-of-charge oil reception facilities.

13 The presence of man-made radionuclides is clearly detectable in the North Sea, but exposure levels are low and should not give cause for concern. Normal operations of nuclear power plants do not generate significant inputs, and only the fuel reprocessing plants at Cap de la Hague and Sellafield give rise to concentrations detectable outside the immediate locality. Concentrations in the environment continue to fall, following the introduction of new processes and improvements in effluent treatment.

14 Fisheries management has thus far not been able to exercise effective control of the fishing effort on a number of North Sea stocks. This is partly the result of the long-term under-reporting and misreporting of catch statistics, which have led to a deterioration in the quality of the data used to assess the effects of fishing. Improvements in the catch statistics reported are urgently required. Fishing also leads to the incidental mortality of non-commercial fish species, benthos, certain species of seabirds, and marine mammals, when they are taken as by-catch. Information on the relative impact of different gears is not complete, and an accurate assessment of the overall impact on the species affected is not yet possible. The collection of appropriate by-catch data has high priority.

15 Tourism, coastal development, and recreational activity all impose severe pressures on wildlife habitats, particularly around the Southern Bight, the German coast, and the west coast of Denmark. The number of areas totally unaffected or only minimally affected by development or general accessibility is decreasing.

16 There is now a comprehensive collection of information on the status of the North Sea. However, the North Sea is such a complex system that a thorough understanding of it as an ecosystem will probably never be attained. Certain gaps in knowledge are particularly evident:

i) There is an urgent need to maintain long-term time series of data, especially those relevant to climate change such as the Continuous Plankton Recorder and the Helgoland time series, and to develop new *in situ* instrumentation for future monitoring of long-term change. The need for the possible establishment of new time series of biological, chemical, and physical indicators of change should be examined.

ii) There is a need for more and better quality input data and information on both point and diffuse sources amenable to control.

iii) There is a need for further coordination of model development and better understanding of the transport and fate of pollutants both in the water column and on suspended particulates.

iv) There is a need for assessment criteria and clearer understanding of and agreement on background concentrations and the development of ecological objectives for the North Sea.

v) There is a need to develop sensitive new techniques for detecting additional substances and adverse effects on marine organisms and, if at all possible, to increase the specificity of existing techniques.

vi) There is a need to maintain and improve long-term fisheries surveys and catch records.

17 All of the above will require the deployment of resources over and above those now available in most countries. Additional resources will also be required to update this *QSR* in the future. Whatever mechanism is selected, it is not realistic to expect the necessary resources to be provided without either additional funding or redeployment of existing efforts.

18 Overall, this assessment leads to the conclusion that although the measures already taken to protect the North Sea are effective, there is a need for continued and in some cases further action. There are local problems in the coastal waters of all countries, and certain areas – in particular the Belgian and the Dutch coasts, the Wadden Sea, the German Bight, the Kattegat, certain Norwegian fjords, most of the tidal estuaries, and possibly parts of the Dogger Bank – are under severe pressure from the combined effects of some or all of the following: fishing, contamination, eutrophication, coastal construction work, industrial activities, shipping, and tourism.

CHAPTER 7

Conclusions

– and outlook

– et perspectives

7.1.

Introduction

This chapter is derived from the scientific assessments in Chapters 1–6 in order to summarize relevant issues of concern, to evaluate the results of agreed measures, and to make recommendations for further action. The recommendations include possible steps to close gaps in knowledge and meet the need for additional measures, presenting options for policies where appropriate. Eight principal topics are discussed: 1) Metals and organic contaminants, 2) Petroleum hydrocarbons, 3) Nutrients and eutrophication, 4) Radioactivity, 5) Litter, 6) Microbiological pollution, 7) Fisheries and mariculture, and 8) Species and habitats. Each topic is subdivided as follows:

a) *Issues of concern*
Reasons for concern and their implications, based on the preceding chapters.

b) *Agreed measures*
Internationally agreed decisions and recommendations on relevant issues, summarized and set off from the rest of the text.

c) *Effects of measures taken*
Descriptions of the way in which the implementation of agreed measures has or has not led to planned or expected improvements, based on the preceding chapters.

d) *Recommendations*
Aimed at protecting and, where relevant, improving the quality of the North Sea environment, and based on the findings of scientific research cited in the preceding chapters, the NSTF recommendations relating to:

- new measures concerning issues for which no measures have been taken until now;
- enhanced application of certain regulations, directives, and measures already agreed, and, if appropriate, extension of the geographical coverage within the North Sea catchment area;
- scientific research to increase the level of knowledge recognized as necessary in order to underpin new policies.

Assessing the success or effectiveness of and continued scientific rationale for current policies aimed at resolving issues of concern for the health of the North Sea, including the effects of human activities, is a difficult exercise for the following reasons:

- Although relationships can be observed between inputs of contaminants from upstream and coastal

7.1.

Introduction

Le présent chapitre découle des évaluations scientifiques figurant aux Chapitres 1 à 6, et vise à résumer les problèmes préoccupants dans ce secteur, à apprécier les résultats des mesures convenues, et à recommander des mesures de suivi. Les recommandations portent entre autres sur les mesures susceptibles d'être prises afin de combler les lacunes des connaissances et sur les mesures complémentaires éventuellement nécessaires, et présentent les options politiques le cas échéant. Huit grands thèmes sont abordés: 1) Métaux et polluants organiques, 2) Hydrocarbures de pétrole, 3) Nutriments et eutrophisation, 4) Radioactivité, 5) Ordures, 6) Pollution microbiologique, 7) Pêche et mariculture, et 8) Espèces et habitats. Chacun des thèmes est subdivisé de la manière suivante:

a) *Problèmes préoccupants*
Motifs des préoccupations et leurs conséquences, découlant des chapitres précédents.

b) *Mesures convenues*
Décisions et recommandations convenues à l'échelon international sur les questions pertinentes, résumées et distinguées du reste du texte.

c) *Effets des mesures prises*
La mise en oeuvre des mesures convenues a-t-elle ou n'a-t-elle pas abouti aux améliorations prévues ou attendues; et raisons de cet état de choses, telles qu'elles découlent des chapitres précédents.

d) *Recommandations*
Recommandations visant à protéger et, s'il y a lieu, à améliorer la qualité du milieu de la mer du Nord, et, selon les résultats de la recherche scientifique donnés dans les chapitres précédents, recommandations du NSTF à savoir:

- de nouvelles mesures relatives à des domaines au titre desquels aucune mesure n'a encore été prise;
- le renforcement de la mise en oeuvre de certaines recommandations, directives et mesures d'ores-et-déjà convenues, et, le cas échéant, extension de la couverture géographique dans le bassin hydrographique de la mer du Nord;
- la recherche scientifique visant à développer les connaissances considérées comme nécessaires à la création des bases des nouvelles politiques.

Apprécier le succès ou l'efficacité des politiques en vigueur, ainsi que la pérennité de l'argumentation scientifique, qui vise à résoudre les problèmes à l'origine des préoccupations pour l'état de la mer du Nord, y compris les effets des activités de l'homme, est un exercice difficile, et ce pour les raisons suivantes:

- Bien que des rapports puissent être constatés entre les apports de polluants venant des Etats en amont et des Etats côtiers states and the concentrations of contaminants in coastal areas, no clear relationships have yet been shown between inputs and concentrations in offshore areas of the North Sea. Some persistent contaminants may lead to local pollution, but others may be dispersed by winds and currents before appearing at detectable, and possibly polluting, levels in organisms, sea water, or sediments.

- The response time of the ecosystem is relatively long. The interval between human activity (e.g., reducing the input of substances or constructing coastal protection works) and the time when the effects of this activity on the ecosystem become noticeable, is normally rather long because of the complex nature of the ecosystem.
- Natural variability makes it difficult to identify human-induced changes over time, and attributing causes to observed effects is an even more uncertain process. As a result of natural variability, for example, it is still difficult to link inputs of contaminants to the North Sea, and especially trends in inputs, with concentration levels in the North Sea, even in those cases where there is a fairly clear picture of input levels, the relative importance of various routes of entry, and distribution patterns. Because of this variability, effects of abatement measures may not be observed and, at the same time, anthropogenic inputs may remain unnoticed. The same is true of the identification of the effects of fisheries on the North Sea ecosystem.
- An assessment of whether there is a need for additional regulatory measures to resolve the issues of concern is to a certain extent hampered by a lack of quantitative objectives. In response to this, at the request of the Third International Conference on the Protection of the North Sea, the North Sea Task Force began consideration of the development of ecological objectives that could form a solid basis for the protection of the North Sea.

Because of these uncertainties the Principle of Precautionary Action was introduced.

d'une part, et d'autre part les teneurs en polluants dans les zones côtières, aucune corrélation claire n'a encore été mise en évidence entre les apports et les teneurs dans les zones de haute mer, en mer du Nord. Certains polluants persistants peuvent créer une pollution locale, tandis que d'autres peuvent être dispersés par les vents et par les courants avant qu'ils ne se manifestent à des teneurs décelables, voire même à des teneurs polluantes, dans les organismes, dans l'eau de mer ou dans les sédiments.

- Le délai de réaction de l'écosystème est relativement long. L'intervalle entre les activités de l'homme (par exemple, la réduction des apports de substances ou la construction d'ouvrages de protection des côtes) et le moment où les conséquences que cette activité a sur l'écosystème se font jour, est en général assez long, ceci en raison même de la complexité de l'écosystème.
- La variabilité naturelle fait qu'il est difficile d'isoler l'évolution due à l'homme au fil du temps, tandis que remonter des effets observés aux causes correspondantes est encore plus incertain. Par exemple, du fait de la variabilité naturelle, il est toujours difficile de corréler les apports de polluants à la mer du Nord, et plus particulièrement les tendances des apports, aux teneurs en mer du Nord, même lorsque l'on a un panorama assez clair du niveau des apports, de l'importance relative des diverses voies de pénétration, et des profils de distribution. En raison même de cette variabilité, il se peut fort bien qu'il soit impossible de déceler les effets des mesures de réduction, tandis que par la même occasion, les apports anthropogènes peuvent fort bien échapper à l'observation. Ceci est également vrai de la détermination des effets que la pêche a sur l'écosystème de la mer du Nord.
- Du fait de l'absence d'objectifs quantitatifs, il est passablement difficile de savoir si de nouvelles réglementations permettraient de résoudre les problèmes préoccupants. Compte tenu de cet état de choses, à la requête de la troisième Conférence internationale sur la protection de la mer du Nord, le Groupe d'intervention mer du Nord (NSTF) a commencé à définir des objectifs écologiques, susceptibles de créer une base saine pour la protection de la mer du Nord.

C'est du fait de ces incertitudes que le principe de l'action de précaution a été adopté.

7.2.

Metals and organic contaminants

Issues of concern

Metals in sea water can be an issue of concern as contaminants because they can accumulate in the tissues of marine organisms. Industrial pollution and run-off from urban areas are important contributors of metal inputs, as are atmospheric sources. Relatively high cadmium concentrations have been found in the open North Sea, e.g., in the liver of fish from the Dogger Bank area. Antagonistic action of metals may mitigate certain toxic effects in marine organisms.

Cadmium and mercury are a matter of concern because they bioaccumulate in the kidneys and liver of top predators (seals, porpoises). Although the inputs of lead are declining, lead found in shellfish may cause local problems.

Organic contaminants are easily taken up by marine organisms. Some of these contaminants are known to have serious toxic effects. Marked effects of tri-

7.2.

Métaux et polluants organiques

Problèmes préoccupants

La présence de métaux dans l'eau de mer peut constituer un problème de contamination préoccupant car ils peuvent en effet s'accumuler dans les tissus des organismes marins. La pollution due aux industries et le ruissellement dans les zones urbaines contribuent largement aux apports de métaux, de même que les sources atmosphériques. L'on a observé, en haute mer du Nord, des teneurs relativement élevées en cadmium, par exemple dans le foie du poisson pêché dans la zone du Dogger Bank. L'antagonisme entre les métaux est susceptible d'atténuer certains effets toxiques chez les organismes marins.

Le cadmium et le mercure sont des métaux préoccupants, car ils sont bioaccumulés dans les reins et dans le foie des prédateurs supérieurs (phoques, marsouins). Bien que les apports de plomb soient en baisse, le plomb décelé chez les mollusques et les crustacés peut donner lieu à des problèmes localement.

Les organismes marins prélèvent sans difficulté les polluants organiques. On sait que certains de ces polluants ont des effets butyl tin (TBT) are found in various coastal areas and shipping lanes, and particularly in estuaries. Certain organic contaminants readily bind to lipids (fat material) and are often stored in lipid-rich tissues where they accumulate, with time. Polychlorinated biphenyls (PCBs) and other contaminants are frequently found in fish liver, seal blubber, bird eggs, and human fat. Elevated levels of PCBs and other contaminants have been found in fish liver, especially from the southern North Sea, and elevated concentrations have also been found in surface sediments in the Norwegian Trench.

The more usual concerns over pollution from these contaminants involve their effects in low to moderate doses over time. Such effects are complex and may affect the immune systems of animals. Organochlorines, in particular PCBs, are associated with impaired reproductive ability in seals and whales.

Agreed measures

As a matter of principle, the Third International Conference on the Protection of the North Sea agreed that all substances that are persistent, toxic, and liable to bioaccumulate, and that could reach the marine environment, should, regardless of their anthropogenic sources, be covered by reduction measures as agreed upon at the Second International Conference on the Protection of the North Sea and, furthermore, that discharges of these substances should be reduced before the year 2000 to levels that are not harmful to man or nature.

The reduction goal was elaborated in the form of a list of 36 substances reaching the North Sea via rivers and estuaries and a sub-set of 17 substances via atmospheric emissions. For the most harmful substances, and explicitly in the case of dioxins, mercury, cadmium, and lead, a reduction of total inputs (via all pathways) of the order of 70% or more was adopted.

Furthermore, specific measures were agreed upon with respect to:

- the control of the use of pesticides;
- the phasing out of use and the destruction of all identifiable PCBs and hazardous PCB-substitutes;
- the discharge and use of chemicals in the offshore industry;
- requirements for cargo unloading from chemical tankers and for discharges of chemical wastes and residues by ships.

Since 1987, the Paris Commission (PARCOM) has adopted decisions and recommendations to control pollution by chemicals. Recommendations endorsing such pollution-control strategies as the use of the Best Available Technology and the Principle of Precautionary Action have been adopted. The latter recommendation explicitly takes into account paragraph XVI, on the Principle of Precautionary Action, from the Second International Conference on the Protection of the North Sea.

Recent decisions of the Paris Commission have concerned mercury discharges from sectors other than the chlor-alkali industry, cadmium discharges, hexachlorocyclohexane (HCH), and refineries.

The European Economic Community (EEC) has passed several pieces of legislation of direct impor-

toxiques graves. On constate notamment l'influence prononcée du tributyl étain (TBT) dans diverses zones côtières et certains couloirs de navigation, et plus particulièrement dans les estuaires. Certains polluants organiques se fixent directement sur les lipides (graisse) et sont souvent stockés dans les tissus riches en lipides où ils s'accumulent au fil du temps. Des polychlorobiphényls (PCB) et autres polluants sont fréquemment décelés dans le foie du poisson, dans la graisse des phoques, les oeufs des oiseaux et la graisse humaine. De hautes teneurs en PCB et autres polluants ont été constatées dans le foie du poisson, surtout chez celui pêché dans le sud de la mer du Nord, et de hautes teneurs ont par ailleurs été constatées dans la strate superficielle des sédiments de la fosse de Norvège.

En ce qui concerne la pollution due à ces polluants, les préoccupations les plus courantes sont dues aux effets qu'ils ont dans le temps à doses faibles à modérées. Ces effets sont complexes, et peuvent influer sur les défenses immunitaires des animaux. Les organochlorés, et plus particulièrement les PCB, ont un rapport avec la baisse de la faculté de reproduction des phoques et des baleines.

Mesures convenues

A titre de principe, la troisième Conférence internationale sur la protection de la mer du Nord est convenue que toutes les substances persistantes, toxiques et susceptibles de bioaccumulation, capables d'atteindre le milieu marin, devaient, quelle que soit leur origine anthropogène, faire l'objet des mesures de réduction convenues à la deuxième Conférence internationale sur la protection de la mer du Nord, et que, de plus, il convenait de réduire les rejets de ces substances avant l'an 2000, et de les ramener à des niveaux inoffensifs pour l'homme ou pour la nature.

Tel qu'il a été élaboré, l'objectif de réduction se présente tant sous la forme d'une liste de 36 substances qui parviennent à la mer du Nord par les cours d'eau et les estuaires que sous la forme d'une sous-série de 17 substances qui transitent par l'atmosphère. Dans le cas des substances les plus nocives, et explicitement dans le cas des dioxines, du mercure, du cadmium et du plomb, un objectif de réduction de l'ensemble des apports (par toutes les voies) de l'ordre de 70% ou plus a été adopté.

De plus, des mesures particulières ont été convenues dans les domaines suivants:

- lutte contre l'utilisation des pesticides;
- abandon et destruction de tous les PCB identifiables, et des succédanés dangereux des PCB;
- rejet et emploi des produits chimiques dans l'industrie de l'offshore;
- exigences relatives aux opérations de déchargement des navires qui transportent des produits chimiques, et exigences relatives aux rejets de produits et de résidus chimiques par les navires.

Depuis 1987, la Commission de Paris (PARCOM) a adopté des décisions et des recommandations qui visent à combattre la pollution par les produits chimiques. Des recommandations, entérinant ces stratégies de lutte contre la pollution, de même que le recours à la meilleure technologie disponible et au principe de l'action de précaution, ont été adoptées. La dernière de ces recommandations tient explicitement compte du paragraphe XVI de la Déclaration issue de la deuxième Conférence internationale sur la protection de la mer du Nord, paragraphe relatif à l'action de précaution.

Les décisions récemment prises par la Commission de Paris portent sur les rejets de mercure des secteurs autres que l'industrie de l'électrolyse des chlorures alcalins, sur les rejets de cadmium, d'hexachlorocyclohexane (HCH), ainsi que sur ceux des raffineries.

tance to the management of the North Sea ecosystem. A key item is EEC Directive 76/464/EEC on Pollution Caused by Certain Dangerous Substances Discharged into the Aquatic Environment of the Community, and its daughter directives. The EEC undertook to establish internationally and regionally applicable criteria for the identification of dangerous substances, with the aim of developing a selection scheme, and subsequently to use this scheme in order to compile a draft list of additional priority substances.

The discussion within the International Maritime Organization (IMO) on the use of tributyl tin (TBT) has resulted so far only in the adoption in 1990 of a resolution requesting the greatest possible reduction in the use of TBT in anti-fouling paints for sea-going ships and the investigation of alternative possibilities. IMO plans to return to the issue in 1994. EEC Directives 76/769/EEC and 89/677/EEC are relevant to the control of TBT.

At the Sixth Trilateral Governmental Wadden Sea Conference (1991), Ministers agreed to achieve significant reductions (of 50% or more) in total inputs of polycyclic aromatic hydrocarbons (PAHs) and organotin compounds to the Wadden Sea.

For two major international rivers entering the North Sea, the Rhine and the Elbe, international cooperation exists with a view to protecting the rivers themselves and to contributing to the protection of the North Sea. The International Commission for the Protection of the River Rhine is implementing the Rhine Action Programme, which, *inter alia*, aims at a 50% reduction of 42 priority substances between 1985 and 1995. An Agreement for the protection of the Elbe (under the auspices of the International Commission for the Protection of the River Elbe) was signed by Germany, Czechoslovakia, and the European Economic Community in 1990. This Commission has also established an action programme, taking into account the need to overcome the great differences in technological standards in the former German Democratic Republic and in the former Czechoslovakia. A substantial financial investment will be needed to achieve the goals of the programme. For other international rivers, the Meuse and the Scheldt, international cooperation is being established.

Effects of measures taken

Management actions have resulted in a distinct decrease in the inputs of certain chemical substances. Some metal inputs are clearly decreasing, as reflected in the lower concentrations found in water, sediments, and/or biota. For instance, concentrations of lead in Norwegian fjords have decreased since 1985, and in the central Dutch coastal zone a significant decrease in concentrations of cadmium, lead, copper, zinc, and chromium in sediments was observed between 1981 and 1991. However, concentrations do not always reflect the local reduction of inputs and may even be increasing. Concentrations of lead were found to be high in sediments off the northeast coast of England, in the Tail End region of the Dogger Bank, and in the Norwegian Trench, owing to long-range transport. The downward trends in metal concentrations related to biota noted in the 1987 *QSR* are continuing, with a few exceptions in the Oslofjord (mercury), the Seine

La Communauté économique européenne (CEE) a adopté plusieurs instruments juridiques qui concernent directement la gestion de l'écosystème de la mer du Nord. L'un des éléments clefs est la Directive 76/464/CEE concernant la pollution causée par certaines substances dangereuses déversées dans le milieu aquatique de la Communauté, ainsi que ses directives connexes. La CEE s'est engagée à définir des critères applicables au plan international et au plan régional, visant à identifier les substances dangereuses, le but étant de mettre sur pied un plan de sélection, puis d'exploiter ce plan de manière à dresser un projet de liste complémentaire de substances prioritaires.

Les entretiens intervenus au sein de l'Organisation maritime internationale (OMI) sur l'utilisation du tributyl étain (TBT) n'ont à ce jour conduit qu'à l'adoption, en 1990, d'une résolution demandant la plus forte réduction possible de la proportion de TBT dans les peintures anti-salissures des navires de haute mer, ainsi que l'étude des alternatives au TBT. L'OMI a l'intention de revenir sur cette question en 1994. Les Directives 76/769/CEE et 89/677/CEE sont pertinentes à la lutte contre les TBT.

A la sixième Conférence gouvernementale trilatérale sur la mer des Wadden (1991), les Ministres sont convenus d'obtenir de fortes réductions (de 50% ou plus) de l'ensemble des apports d'hydrocarbures polycycliques aromatiques (HPA) et de composés organostanniques à la mer des Wadden.

Dans le cas de deux grands fleuves internationaux qui se jettent en mer du Nord, à savoir le Rhin et l'Elbe, la coopération internationale a pour but de protéger ces fleuves eux-mêmes, tout en contribuant à la protection de la mer du Nord. La Commission internationale pour la protection du Rhin met en oeuvre le Programme d'action du Rhin, lequel, entre autres, vise à faire baisser de 50% les apports de 42 substances prioritaires de 1985 à 1995. L'Accord sur la protection de l'Elbe (conclu sous les auspices de la Commission internationale de la protection de l'Elbe) a été signé par l'Allemagne, la Tchécoslovaquie et la Communauté économique européenne en 1990. Cette Commission a par ailleurs mis sur pied un programme d'action, qui tient compte de la nécessité de supprimer les obstacles suscités par les grandes différences de normes technologiques de l'ancienne République démocratique allemande et de l'ancienne Tchécoslovaquie. Un gros investissement sera nécessaire pour pouvoir réaliser les objectifs du programme en question. Dans le cas de la Meuse et de l'Escaut, autres fleuves internationaux, on met en place à l'heure actuelle une coopération internationale.

Effets des mesures prises

Les mesures de gestion ont abouti à une nette baisse des apports de certaines substances chimiques. Certains apports de métaux baissent nettement tel que démontré par des teneurs en diminution trouvées dans les eaux, les sédiments et/ou le biote. Par exemple, les teneurs en plomb présentes dans les fjords norvégiens ont baissé depuis 1985, tandis que dans la région centrale de la zone côtière néerlandaise, une baisse significante des teneurs en cadmium, en plomb, en cuivre, en zinc et en chrome a été constatée dans les sédiments de 1981 à 1991. Toutefois, les teneurs ne reflètent pas toujours la baisse locale des apports, et il arrive même qu'elles soient en hausse. L'on a en effet constaté la présence de hautes teneurs en plomb dans les sédiments au large de la côte nord-est de l'Angleterre, dans la région de Tail End du Dogger Bank, ainsi que dans la fosse de Norvège, le plomb étant en effet charrié sur de grandes distances. Les tendances à la baisse des teneurs en métaux dans le biote, signalées dans le *QSR* 1987 se poursuivent, avec quelques rares exceptions dans le fjord d'Oslo (mercure), l'estuaire de la Seine (cadmium et plomb) ainsi que la mer des Wadden et l'estuaire de l'Elbe (plomb, cuivre et cadmium).

Estuary (cadmium and lead), and the Wadden Sea and the Elbe Estuary (lead, copper, and cadmium).

Trends in the concentrations of trace organic contaminants are difficult to assess. In the Oslofjord, for example, a decreasing trend in PCB concentrations in biota was observed between 1985 and 1989, and it has been fluctuating since 1990. In the Firth of Forth, a marked decrease in hexachlorobenzene (HCB) concentrations has been reported in response to local input reductions. It is as yet impossible to draw firm conclusions with respect to the effects of expected input reductions on North Sea ecosystems.

Further research is needed on the sources and biological effects of PAHs.

Recommendations

General

In order to assess the degree of pollution by chemical substances, an agreement on background concentrations of natural compounds is required.

The achievement of substantial emission reductions by 1995 that is now under way for many substances makes it imperative to develop policies to ensure that the reductions are at least maintained after 1995.

Large quantities of chemicals are used offshore by the oil industry. Their use and discharge to the marine environment are not sufficiently controlled, and measures need to be introduced through the Paris Commission to regulate and reduce such emissions of chemicals from offshore platforms.

Heavy metals

The existing reduction goals for inputs of metals to the North Sea should be implemented. The high concentrations of cadmium found in liver tissue of fish from the central North Sea indicate that cadmium is a priority substance in this respect and could be made subject to more stringent and specific reduction goals for atmospheric emissions.

In general, there is a need to pay more attention to reduction measures directed towards atmospheric emissions of heavy metals.

Organic contaminants

For many organic contaminants, no conclusions can be drawn as to whether the existing goals and measures are sufficient. For some substances, however, such as TBT and hexachlorocyclohexane (HCH), there is evidence of serious problems, which provide the basis for concluding that more stringent goals and measures are urgently needed. Therefore, further reductions in the use of TBT, or even a ban on its use, should have high priority, especially in areas where measures to date have had little effect. The possible total ban on the use of TBT also implies the need to identify safe substitution products.

For other organic substances (e.g., PCBs and DDT), there is a policy against their production and use. Concentrations in the marine environment indicate that there are still problems. It is important that sources of PCBs and DDT be located so that adequate strategies can be developed to prevent them from entering the environment.

There are also substances (e.g., PAHs) that have not yet been identified as priority substances within the framework of the North Sea Conferences, although they are found in the North Sea in concentra-

Les tendances des teneurs des polluants organiques en traces sont difficiles à apprécier. Par exemple, dans le fjord d'Oslo, une tendance à la baisse des teneurs en PCB dans le biote a été observée de 1985 à 1989, les tendances fluctuant cependant depuis 1990. Dans le Firth of Forth, une nette baisse des teneurs en hexachlorobenzène (HCB) a été signalée, ceci après la réduction des apports locaux. Il n'est pas encore possible de tirer des conclusions définitives sur les effets des réductions probables des apports aux écosystèmes de la mer du Nord.

De plus amples recherches sont nécessaires sur les sources et sur les effets biologiques des HPA.

Recommandations

Généralités

Pour pouvoir apprécier l'ampleur de la pollution due aux substances chimiques, il convient de se mettre d'accord sur les teneurs ambiantes des composés naturels.

La réduction substantielle des émissions, qui doit intervenir d'ici 1995, et qui est en cours à l'heure actuelle dans le cas de nombre de substances, fait qu'il est impératif d'élaborer des politiques qui assureront au moins la pérennité des réductions au-delà de 1995.

L'industrie pétrolière consomme en offshore de grandes quantités de produits chimiques. Leur emploi et leur rejet dans le milieu marin ne sont pas suffisamment contrôlés, des mesures devant être mises en place par le truchement de la Commission de Paris afin de réglementer et de réduire lesdites émissions de produits chimiques par les plates-formes en offshore.

Métaux lourds

Les objectifs de réduction actuels des apports de métaux à la mer du Nord devraient être mis en oeuvre. Les hautes teneurs en cadmium, dont on constate la présence dans le tissu du foie du poisson capturé dans la région centrale de la mer du Nord, indiquent que le cadmium est à cet égard une substance prioritaire, et que ses émissions atmosphériques pourraient faire l'objet d'objectifs de réduction plus rigoureux et plus spécifiques.

D'une façon générale, il y a lieu de prêter une attention toute particulière aux mesures de réduction visant les émissions atmosphériques de métaux lourds.

Polluants organiques

Dans le cas de nombre de polluants organiques, aucune conclusion ne peut être tirée sur le fait de savoir si les objectifs et les mesures actuels suffisent. Toutefois, dans le cas de certaines des substances, telles que le TBT et l'hexachlorocyclohexane (HCH), l'on a la preuve de problèmes graves, qui permettent de conclure que des objectifs et des mesures plus rigoureux sont d'urgence nécessaires. Par conséquent, il convient d'accorder une haute priorité aux nouvelles baisses de la consommation du TBT, voire même à son interdiction pure et simple, surtout dans les zones, où, à ce jour, les mesures n'ont guère eu d'effets. L'interdiction totale éventuelle du TBT implique par ailleurs qu'il faut disposer de succédanés sans danger.

Dans le cas d'autres substances organiques (par exemple, les PCB et le DDT), il existe d'ores-et-déjà une politique qui va à l'encontre de leur fabrication et leur utilisation. Dans le milieu marin, les teneurs observées indiquent que des problèmes se posent toujours à cet égard. Il est important que les sources de PCB et de DDT soient localisées, de telle sorte que des stratégies adéquates puissent être élaborées afin d'empêcher leur pénétration dans l'environnement.

Il existe par ailleurs des substances (par exemple, les HPA) qui ne sont pas considérées comme des substances prioritaires dans le contexte des Conférences sur la mer du Nord, ceci en dépit du fait qu'elles aient été observées en mer du Nord à des teneurs qui sont susceptibles de porter atteinte aux écosystèmes.

tions that may affect the health of the ecosystems. For these substances, reduction policies should be considered. In order to reduce emissions of PAHs, international goals and measures are required, and attention should be paid to emissions to water as well as to the air, for both land-based and sea-based sources.

There are a large number of synthetic organic chemicals in current use that may, on the basis of comparative toxicity and other studies, be toxic and persistent if they are discharged into the marine environment and may, thus, affect marine life. Many of these chemicals are difficult to characterize in marine samples and are commonly referred to by chemists as 'unknown' substances. There is a need to evaluate the relative risk from different groups of these substances in terms of toxicity, persistence, and amounts produced and potentially discharged into the sea. High-risk substances should be strictly regulated and their use phased out, even though there is insufficient information on their occurrence in sea water, sediments, and marine biota.

The Precautionary Principle is applicable to substances that are toxic and persistent and detectable in the marine environment.

Research

Knowledge about which synthetic organic compounds occur in the North Sea and at what concentrations is scarce. The effects of PCBs on the susceptibility of seals to infectious diseases and on their reproductive capacity require attention. The effects of co-toxicant (combining organic substances and metals) anti-fouling substances on ecosystems also need clarification. In general, information is still needed on the relationship between inputs of organic contaminants and the concentrations of these contaminants observed in sediments and biota and their effects on the latter.

Assessment tools

Current policy and its expected results, as well as the recommendations contained in this chapter, will substantially reduce the number and seriousness of issues of concern. However, appropriate methodology is lacking by which to assess whether contaminant concentrations in the various parts of the North Sea, including coastal areas, estuaries, and fjords, will have reached levels by the year 2000 that are no longer harmful to man or nature. Therefore, there is a need to develop adequate and duly validated tools to assess the progress in reaching this goal. These tools should make use of background levels and, where this is not possible or feasible, of ecotoxicological information. For specific coastal areas, estuaries, and fjords, detailed assessments should be conducted. Consequently, in developing the assessment tools, the fact that these areas may have different background levels, or differences in vulnerability to specific substances, must be taken into account.

Monitoring to evaluate the effectiveness of regulatory measures should be carried out as close as possible to the sources of inputs and in sedimentation areas.

Dans le cas de ces substances, il conviendrait d'envisager des politiques de réduction. Pour pouvoir réduire les émissions de HPA, des objectifs et des mesures doivent être mis en place à l'échelon international, une attention devant être accordée tant aux émissions dans le milieu aquatique qu'aux émissions atmosphériques, et ceci aussi bien dans le cas des sources telluriques que des sources marines.

On utilise à l'heure actuelle un grand nombre de produits chimiques organiques de synthèse, lesquels sont susceptibles, selon les résultats des études de toxicité comparatives et autres, d'être toxiques et persistants s'ils sont rejetés dans le milieu marin, et qui peuvent donc porter atteinte à la vie marine. Nombre de ces produits chimiques sont difficiles à isoler dans les échantillons prélevés sur le milieu marin, les chimistes les taxant en général de substances «inconnues». Il convient d'apprécier le risque relatif encouru du fait des divers groupes de substances en cause, ceci sur le plan de la toxicité et de la persistance, ainsi que sur celui des quantités produites et susceptibles d'être rejetées en mer. Il convient de réglementer rigoureusement les substances à haut risque, et d'abandonner leur exploitation, même si l'on ne dispose pas d'éléments d'information suffisants sur leur présence dans l'eau de mer, les sédiments et le biote marin.

Le principe de l'action de précaution s'applique aux substances toxiques, persistantes et décelables dans le milieu marin.

Recherche

Il existe peu d'information sur les composés organiques de synthèse présents en mer du Nord ainsi que sur leurs teneurs. Les effets des PCB sur la sensibilité des phoques aux maladies infectieuses et sur leur capacité de reproduction demandent à être étudiés. Les effets que les substances anti-salissures co-toxiques (dans lesquelles des substances organiques sont combinées à des métaux) ont sur les écosystèmes demandent aussi à être clarifiés. D'une façon générale, il convient de mieux se renseigner sur le rapport entre les apports de polluants organiques d'une part, et d'autre part les teneurs de ces polluants, telles que constatées dans les sédiments et dans le biote, ainsi que leurs effets sur ceux-ci.

Outils d'évaluation

La politique actuelle, et les résultats qu'elle devrait avoir, de même que les recommandations du présent chapitre, permettront de réduire considérablement le nombre et la gravité des problèmes à l'origine des préoccupations. Toutefois, l'on ne dispose d'aucune méthodologie qui permettrait de savoir si les teneurs en polluants dans les diverses parties de la mer du Nord, y compris les zones côtières, les estuaires et les fjords, auront été ramenées, d'ici l'an 2000, à des teneurs qui auront cessé d'être nocives pour l'homme ou pour la nature. Il est donc nécessaire de créer des outils appropriés et dûment validés, pour pouvoir apprécier les progrès accomplis dans le sens de cet objectif. Il conviendrait que ces outils exploitent les teneurs ambiantes et, lorsque ceci est impossible ou irréalisable, qu'ils fassent appel aux éléments d'information écotoxicologiques. Par ailleurs, des évaluations approfondies devraient être réalisées dans le cas de certaines zones côtières, ainsi que de certains estuaires et fjords. En conséquence, dans l'élaboration des outils d'évaluation, le fait que dans ces zones les teneurs ambiantes soient différentes, ou encore que la vulnérabilité à telle ou telle substance soit différente, doit impérativement être pris en compte.

Il conviendrait de procéder aux contrôles nécessaires à l'appréciation de l'efficacité des mesures réglementaires en des points aussi proches que possible des sources des apports, ainsi que dans les zones sédimentaires.

7.3.

Petroleum hydrocarbons

Issues of concern

The size of the area affected by discharges of oil from offshore activities, together with the duration of known effects and the uncertainty about long-term effects, are subjects of concern. Until recently, oiled cuttings have represented an important input of oil to the North Sea. A consequence of this is that some fish caught in the vicinity of platforms have been contaminated by oil from drilling muds. Production water is expected to make an increasingly greater contribution to the total input of oil, while improvements in cuttings cleaning technology and the types of oils used have led to reductions in this source of input in recent years.

Of greater concern are the quantities of oil from illegal discharges by ships and from incomplete gas flaring on oil platforms. Oiled carcasses of birds are still found in abundance along North Sea coastlines and may serve as indicators of pollution levels. PAHs are also an issue of concern since they originate from various diffuse sources, e.g., flaring and engines.

Agreed measures

At the Third International Conference on the Protection of the North Sea, Ministers agreed upon a number of specific actions to reduce pollution by oil. A concerted action by North Sea States within the International Maritime Organization (IMO) resulted in a decision to make the more stringent discharge standards for oily waste and residues, which were formerly applicable only in near-coastal zones and Special Areas, applicable in all sea areas on 6 July 1993, with a grace period of five years for ships built before that date. For offshore installations, it was agreed that no contaminated cuttings should be discharged into the sea. Furthermore, it was agreed to investigate the technical feasibility of a reduction from 40 to 30 mg/l in the oil content of production and displacement water discharged from existing and new offshore installations.

Also on 6 July 1993, new regulations for oil tankers entered into force. These regulations require new oil tankers to be designed and constructed with a double hull or any other ship design considered as equivalent by IMO in order to prevent pollution by oil in case of accidents (collision, grounding, etc.). This is in line with the '3 E' (European, Economic, Ecological) technology concept developed by some European countries.

Following the 'Braer' accident, the EEC Council of the Ministers of Transport and of the Environment adopted in January 1993 a decision containing measures to strengthen the control of shipping, to ban substandard ships from European waters, and to reduce the risk of pollution. As required by the Council, the European Economic Community recently adopted a communication on a 'Common Policy on Safe Seas', which presents a coherent programme for the enhancement of marine safety and prevention of pollution from ships, on both the international and the Community level. The document includes initiatives and measures to prevent or reduce operational or accidental pollution (including oil) by ships.

7.3.

Hydrocarbures de pétrole

Problèmes préoccupants

L'ampleur même de la zone touchée par les rejets d'hydrocarbures dûs aux activités en offshore, parallèlement à la durée de leurs effets connus et à l'incertitude qui règne quant à leurs effets à long terme, sont des sujets d'inquiétude. Jusqu'à récemment, les débris chargés d'hydrocarbures représentaient un important apport d'hydrocarbures à la mer du Nord. La conséquence de cet état de choses est que certains poissons capturés à proximité des plates-formes ont été pollués par des hydrocarbures présents dans les boues de forage. Il est probable que la contribution de l'eau de production à l'ensemble des apports d'hydrocarbures ne cessera d'augmenter, alors qu'en revanche, le perfectionnement des techniques de nettoyage des débris, ainsi que les types d'hydrocarbures employés, ont abouti à une baisse de ces apports de ces dernières années.

Le volume des rejets illégaux d'hydrocarbures par les navires, ou encore dûs à l'insuffisance de la combustion des gaz brûlés à la torchère sur les plates-formes pétrolières est plus inquiétant. On trouve toujours de nombreux cadavres d'oiseaux mazoutés sur le littoral de la mer du Nord, ce qui peut constituer un indicateur du niveau de la pollution. Les HPA posent par ailleurs un problème préoccupant, puisqu'ils viennent de diverses sources diffuses, comme par exemple le brûlage à la torchère et les moteurs.

Mesures convenues

A la troisième Conférence internationale sur la protection de la mer du Nord, les Ministres sont tombés d'accord sur une série de mesures visant spécifiquement la lutte contre la pollution par les hydrocarbures. L'action concertée des Etats de la mer du Nord au sein de l'Organisation maritime internationale (OMI) a abouti à la décision de renforcer les normes de rejet des déchets et des résidus d'hydrocarbures, normes qui, auparavant, ne s'appliquaient qu'aux zones proches des côtes ainsi qu'aux zones spéciales, et qui sont, depuis le 6 juillet 1993, applicables à toutes les zones marines, ceci avec un délai de grâce de cinq ans dans le cas des navires construits avant cette date. Dans le cas des installations en offshore, il fut convenu qu'aucun débris de forage pollué ne devait être rejeté en mer. De plus, il fut aussi convenu d'étudier la faisabilité technique d'une réduction de 40 à 30 mg/l de la teneur en hydrocarbures de l'eau de production et de l'eau de déplacement rejetées par les installations actuelles et par les nouvelles installations en offshore.

Par ailleurs, toujours le 6 juillet 1993, de nouvelles réglementations relatives aux pétroliers sont entrées en vigueur. Ces réglementations portent que les nouveaux pétroliers doivent être, dès leur conception et leur construction, équipés d'une double coque, ou doivent être d'une conception considérée comme équivalente par l'OMI, de manière à pouvoir empêcher la pollution par les hydrocarbures en cas de sinistre (collision, échouage, etc.). Ces réglementations sont conformes au concept technologique «3 E» (Européen, Economique, Ecologique) mis au point par certains des pays européens.

A la suite du sinistre du «Braer», les Conseils des Ministres des transports et de l'environnement de la Communauté économique européenne ont adopté, en janvier 1993, une décision portant création de mesures visant à renforcer la réglementation de la navigation, à interdire, dans les eaux européennes, les navires aux caractéristiques inférieures aux normes, et à réduire le risque de pollution. Ainsi que stipulé par le Conseil, la Communauté économique européenne a récemment adopté une communication sur une «politique com-

In order to prevent accidental pollution by ships carrying hazardous cargo, Germany and the Netherlands recently submitted proposals to the Marine Safety Committee of IMO concerning routing measures for such ships. The principle of mandatory routing was accepted and has been further elaborated. In addition, specific changes in the current routing recommendations are also being elaborated, especially for the routing system north of the Wadden Sea islands.

The Paris Commission has been instrumental in achieving substantial reductions in discharges from refineries and offshore installations into the marine environment through the implementation of various programmes and measures established since 1978, such as the Guidelines for Discharges from New Refineries, in 1982, superseded by Recommendation 89/5 applying to existing refineries discharging more than 10 tonnes of oil per year.

Regarding pollution from offshore installations, the Paris Commission has set a 40 mg oil/l target standard for the oil content of effluents discharged from existing and new installations. The Commission has also adopted recommendations on discharges resulting from exploration activities. PARCOM Decision 92/2 on the Use of Oil-Based Muds establishes the principles to be applied to all drilling operations in order to achieve the target standard of an average of 10 g oil/kg dry cuttings.

Apart from these technical measures under the Paris Commission to reduce inputs of oil, the Third International Conference on the Protection of the North Sea agreed:

- to improve control and enforcement and to deter all ships from contravening the requirements of MARPOL 73/78, amongst others, by an increased coastal state jurisdiction via the establishment of Exclusive Economic Zones;
- to improve legal instruments aimed at minimizing accidental oil pollution from ships;
- to improve the availability of shore reception facilities;
- to improve the effectiveness of airborne surveillance.

Effects of measures taken

Over the period 1984–1990 there was a decrease of 30% in the total discharges of hydrocarbons owing to reductions in the discharges of oil-contaminated cuttings. Discharges of oil in production water, however, have increased considerably, and there are still significant quantities of oil from illegal discharges from ships. The release of oil from incomplete gas flaring from oil platforms continues and needs to be quantified.

From the information presented in this report, no real decreasing trend in pollution of the North Sea by oil can be inferred. Nor has there been a general decline in the number of oiled birds found along North Sea coastlines. One exception is the German coast, where reductions have been noted. The question of whether or not reductions can be attributed to the availability of free-of-charge oil reception facilities is now being discussed.

It will take some time before the implementation of the recently agreed measures will have the beneficial effects expected in terms of reduced oil pollution.

mune des mers sans danger», laquelle présente un programme cohérent de renforcement de la sécurité maritime et de la prévention de la pollution par les navires, et ceci aussi bien au niveau international qu'au niveau communautaire. Le document prévoit des initiatives et des mesures visant à prévenir ou à réduire la pollution en exploitation ou la pollution accidentelle (y compris par les hydrocarbures) suscitée par les navires.

Pour empêcher la pollution accidentelle due aux navires qui transportent des cargaisons dangereuses, l'Allemagne et les Pays-Bas ont récemment soumis des propositions au Comité OMI de la sécurité maritime, propositions relatives aux itinéraires devant être empruntés par ce type de navires. Le principe de l'itinéraire obligatoire a été accepté, et a même été développé plus avant. De plus, on met au point en ce moment les amendements qui seront apportés aux recommandations actuelles relatives aux itinéraires, notamment dans le cas de l'itinéraire prévu au nord des îles de la mer des Wadden.

La Commission de Paris a réussi à réduire dans de fortes proportions les rejets, dans le milieu marin, des raffineries et des installations en offshore, ceci grâce à la mise en oeuvre de divers programmes et mesures mis sur pied depuis 1978, tels que les lignes directrices sur les rejets des nouvelles raffineries, adoptées en 1982, puis annulées et remplacées par la Recommandation 89/5 qui s'applique aux raffineries actuelles qui rejettent plus de 10 tonnes d'hydrocarbures par an.

En ce qui concerne la pollution due aux installations en offshore, la Commission de Paris a fixé une norme cible de 40 mg d'hydrocarbures/l quant à la teneur en hydrocarbures des effluents rejetés tant par les installations nouvelles que par les installations actuelles. La Commission a par ailleurs adopté des recommandations relatives aux rejets résultant des opérations de prospection. La Décision PARCOM 92/2 sur l'utilisation des boues au mazout porte création des principes à appliquer à toutes les opérations de forage pour pouvoir respecter la norme cible moyenne de 10 g d'hydrocarbures/kg de débris secs.

Hormis ces mesures techniques, qui émanent de la Commission de Paris, et qui visent à réduire les apports d'hydrocarbures, la troisième Conférence internationale sur la protection de la mer du Nord est convenue:

- d'améliorer entre autres le contrôle et l'application des dispositions de la Convention MARPOL 73/78, et de dissuader tous les navires d'y contrevenir, ceci en renforçant la juridiction de l'Etat côtier par la création de zones économiques exclusives;
- d'améliorer les instruments juridiques visant à minimiser la pollution par les hydrocarbures, telle que provoquée par les sinistres en mer;
- de créer de nouvelles installations de réception sur la côte;
- de renforcer l'efficacité de la surveillance aérienne.

Effets des mesures prises

Pendant la période écoulée de 1984 à 1990, l'on a constaté que dans l'ensemble, les rejets d'hydrocarbures avaient baissé de 30%, ceci du fait de la baisse des rejets de débris pollués par les hydrocarbures. En revanche, les rejets d'hydrocarbures dans l'eau de production ont considérablement augmenté, tandis que, par ailleurs, les quantités d'hydrocarbures dues aux rejets illégaux commis par les navires restent importantes. L'émission d'hydrocarbures due à l'insuffisance de la combustion des gaz aux torchères des plates-formes pétrolières se poursuit, et il conviendrait de la quantifier.

D'après les éléments d'information figurant dans le présent rapport, on ne peut conclure à une baisse réelle de la tendance de la pollution de la mer du Nord par les hydrocarbures. On ne peut constater non plus une baisse générale du nombre d'oiseaux mazoutés trouvés sur le littoral de la mer du Nord. La côte allemande

Recommendations

Oil (from cuttings, production water, flaring operations, and leaks in existing installations) and its effects on fish are still a matter of concern, and reduction efforts should be continued. Further steps may be required.

Regarding shipping, concerted action may be necessary to strengthen the enforcement of reduction measures, for instance by better policing and the prosecution of offenders. Accidental oil pollution from ships remains a main threat to the North Sea and its coastal areas. Further regional measures could be considered to prevent accidental oil pollution and to decrease the chances of oil being washed ashore in the event of accidental pollution.

In 1995 it should be possible to assess the effectiveness of the measures already agreed, and an assessment should be made available to the Fourth International Conference on the Protection of the North Sea. The monitoring of oiled seabirds should continue as a useful indicator of the effectiveness of these measures.

7.4. Nutrients and eutrophication

Issues of concern

Nutrient enrichment of North Sea ecosystems is derived mainly from rivers and land run-off. One matter of concern is the surplus of nitrogen which occurs to a large extent in the form of nitrate. Airborne nitrogen inputs can be of the same order of magnitude as the riverine sources in summer. A substantial fraction of atmospheric inputs comes from motor vehicle emissions.

Events that can be attributed to increased levels of nutrients also occur naturally. When such events have deleterious effects they should be considered pollution. Deleterious effects occur when and where biological manifestations of nutrient enrichment are quantitatively and/or qualitatively out of balance with similar natural events, resulting in changes in: the order of succession, the scale and duration of the development of phytoplankton species, and/or the size structure of phytoplankton populations. The shift in the nitrogen-to-phosphorus ratio may lead to the development of populations of toxic algae. These changes in the population dynamics of the plankton may in turn affect other levels in the food web: the energy transfer processes may be altered, and it is possible that enhanced primary production may not be incorporated into the existing food chains, leading to a change in the structure of invertebrate populations. In extreme cases, when climatic and local oceanographic conditions limit exchange through the water column, this can result in deficits in dissolved oxygen concentrations, killing invertebrates and fish.

The spread of eutrophication effects from the coastal regions that receive high nutrient loads to other regions of the North Sea is an issue of concern. The eastern Skagerrak and Kattegat are affected by both local and long-range transported nutrients and eutrophication. The Dogger Bank is also a region that may be affected by transport from coastal regions, and further research on this is required.

fait exception à cet égard, puisqu'une baisse a été constatée. On débat à l'heure actuelle de la question de savoir si les baisses peuvent être attribuées à la présence d'installations gratuites de réception des hydrocarbures.

Il faudra un certain temps pour que la mise en oeuvre des mesures d'ores-et-déjà convenues ait les effets bénéfiques attendus sur le plan de la réduction de la pollution par les hydrocarbures.

Recommandations

Les hydrocarbures (provenant des débris, de l'eau de production, des opérations à la torchère, et des fuites des installations actuelles) ainsi que leurs effets sur le poisson restent inquiétants, l'effort de réduction devant se poursuivre. Il se peut qu'il soit nécessaire de prendre de nouvelles mesures.

En ce qui concerne la navigation, une action concertée est peut-être nécessaire au renforcement de l'application des mesures de réduction, ceci en améliorant la police et la poursuite des contrevenants. La pollution accidentelle par les hydrocarbures des navires reste l'une des principales menaces pour la mer du Nord et pour ses zones côtières. De nouvelles mesures pourraient être envisagées à l'échelon régional afin d'empêcher la pollution accidentelle par les hydrocarbures, et diminuer les chances de voir des hydrocarbures rejetés sur le littoral dans l'éventualité d'une pollution accidentelle.

En 1995, il devrait être possible d'apprécier l'efficacité des mesures déjà agréées, et une évaluation devrait être soumise à la quatrième Conférence internationale sur la protection de la mer du Nord. Il conviendrait de poursuivre la surveillance des oiseaux de mer mazoutés, bon indicateur de l'efficacité de ces mesures.

7.4. Nutriments et eutrophisation

Problèmes préoccupants

L'enrichissement des écosystèmes de la mer du Nord en nutriments est surtout due aux apports fluviaux et au ruissellement des terres. L'une des questions préoccupantes tient à l'excédent d'azote, présent dans une large mesure sous la forme de nitrates. Pendant l'été, les apports atmosphériques d'azote peuvent être du même ordre de grandeur que les apports fluviaux. Une forte proportion des apports atmosphériques est due aux émissions des véhicules automobiles.

Les phénomènes qui peuvent être attribués à l'augmentation des teneurs en nutriments se manifestent aussi naturellement. Lorsque ces phénomènes ont des effets préjudiciables, il convient alors de les considérer comme des pollutions. Les effets préjudiciables se produisent au moment et aux emplacements où les manifestations biologiques de l'enrichissement en nutriments sont quantitativement et/ou qualitativement déséquilibrées par rapport aux phénomènes naturels analogues, ce qui aboutit à des bouleversements de l'ordre de succession, de l'ampleur et de la durée du développement des espèces du phytoplancton, et/ou de la taille et de la structure des populations du phytoplancton. La modification du ratio azote-phosphore peut aboutir à un développement des populations d'algues toxiques. Ces modifications de la dynamique des populations de plancton peuvent à leur tour influer sur d'autres niveaux de la chaîne alimentaire: les processus de transfert de l'énergie peuvent en effet être bouleversés, tandis qu'il est par ailleurs possible que l'excédent de la production primaire ne puisse être intégré aux chaînes alimentaires existantes, ce qui aboutit à une modification de la structure des populations d'invertébrés. Dans les cas extrêmes, lorsque les conditions climatiques et les conditions océanographiques locales limitent les échanges qui interviennent dans la colonne

Agreed measures

At the Second International Conference on the Protection of the North Sea, Ministers decided to take effective steps at the national level in order to reduce nutrient inputs to areas where they are likely, directly or indirectly, to cause pollution. The aim was to achieve a substantial reduction (of the order of 50%) in the inputs of phosphorus and nitrogen to these areas between 1985 and 1995.

In 1990 the Third International Conference on the Protection of the North Sea reaffirmed this decision and identified some coastal zones of the North Sea, including the Skagerrak and Kattegat, as being actual eutrophication areas and, in view of the increased input levels of nutrients, some other coastal zones as being potential problem areas. In addition, the North Sea Ministers agreed some general guidelines for the elaboration of national measures to implement these decisions.

The Ministerial Meeting of the Oslo and Paris Commissions in 1992 endorsed the Action Plan, which, *inter alia*, aims at the establishment of measures for achieving the 50% reduction goal. In a progress report on Nutrients in the Convention Area, potential eutrophication problem areas were identified. Together with non-binding recommendations on the coordinated programme for the reduction of nutrients, the Oslo and Paris Commissions have adopted practical programmes such as the Algal Pollution Report (ALGPOLREP) system for providing information on monitoring of unusual algal blooms and warnings about threats from such blooms.

EEC Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment and EEC Directive 91/676/EEC of 12 December 1991 concerning nitrates from agricultural sources are relevant to the reduction of nutrient inputs to the North Sea.

Effects of measures taken

Data relating to reductions in inputs of nutrients are now available from Belgium, Denmark, Germany, the Netherlands, Norway, and Sweden. Although a reduction in inputs of nutrients, especially of phosphorus, has taken place, there has been no detectable effect of this reduction in most parts of the North Sea since 1985. Reasons for this could be:

- the difficulty of detecting such effects against the natural background variability and the natural contributions from the Atlantic, which also vary;
- the long time-lag that exists between reductions in inputs and reductions in concentration levels, mainly as a result of the rather efficient internal cycle.

Despite substantial efforts to reduce nitrogen loads, it is expected that the overall 50% reduction target for nitrogen inputs to areas where they are likely, directly or indirectly, to cause pollution, will probably not be reached by 1995, with the measures currently being taken or planned. This is mainly because the reductions expected from the agricultural sector seem to be insufficient. With regard to phosphorus, Belgium, Denmark, Germany, the Netherlands, Norway, and Sweden expect to reach a reduction in inputs of the order of 50% between 1985 and 1995.

d'eau, cette situation peut aboutir à un déficit d'oxygène en solution, déficit qui entraîne la mort des invertébrés et du poisson.

La propagation des phénomènes d'eutrophisation au départ des régions côtières qui reçoivent d'importants apports de nutriments, vers d'autres régions de la mer du Nord, est un problème préoccupant. L'est du Skagerrak et du Kattegat sont touchés par des apports de nutriments d'origine locale et d'origine lointaine, ainsi que par une eutrophisation correspondante. Par ailleurs, la région du Dogger Bank est susceptible d'être touchée par les apports des régions côtières, de nouvelles recherches à cet égard étant nécessaires.

Mesures convenues

A la deuxième Conférence internationale sur la protection de la mer du Nord, les Ministres ont décidé de prendre des mesures concrètes au niveau national, de manière à réduire les apports de nutriments aux zones où ces apports sont susceptibles, directement ou indirectement, de provoquer une pollution. L'objectif était de parvenir à une réduction substantielle (de l'ordre de 50%) des apports de phosphore et d'azote à ces zones de 1985 à 1995.

En 1990, la troisième Conférence internationale sur la protection de la mer du Nord a réaffirmé cette décision, et a défini certaines zones côtières de la mer du Nord, dont le Skagerrak et le Kattegat, comme des zones d'eutrophisation effective; par ailleurs, compte tenu de la croissance des apports de nutriments, elle a défini d'autres zones côtières comme des zones à problème potentiel. De plus, les Ministres de la mer du Nord se sont mis d'accord sur des lignes directrices générales qui permettraient d'élaborer des mesures d'application de ces décisions à l'échelon national.

La réunion ministérielle des Commissions d'Oslo et de Paris, intervenue en 1992 a entériné le plan d'action, lequel, entre autres, vise à instaurer des mesures permettant de réaliser l'objectif de réduction de 50%. Dans un rapport d'avancement sur les nutriments dans la zone de la Convention, les zones à problème potentiel d'eutrophisation ont été définies. Parallèlement à des recommandations non contraignantes sur le programme coordonné de réduction des nutriments, les Commissions d'Oslo et de Paris ont adopté des programmes concrets, tels que le système d'alerte aux pollutions algaires (ALGPOLREP), système qui permet de communiquer des informations sur la surveillance, et de lancer l'alarme en cas de menace due à ces éclosions.

La Directive 91/271/CEE du 21 mai 1991, relative au traitement des eaux usées urbaines, et la Directive 91/676/CEE du 12 décembre 1991, laquelle a trait aux nitrates d'origine agricole, sont pertinentes à la réduction des apports de nutriments à la mer du Nord.

Effets des mesures prises

Des données relatives à la réduction des apports de nutriments sont désormais en possession en Belgique, au Danemark, en Allemagne, aux Pays-Bas, en Norvège et en Suède. Bien qu'une baisse des apports de nutriments, et surtout du phosphore, ait effectivement eu lieu, dans la plupart des zones de la mer du Nord, il s'est avéré impossible de déceler l'effet des réductions ainsi intervenues depuis 1985. Les raisons de cet état de choses sont vraisemblablement les suivantes:

- il est difficile de distinguer ces effets de la variabilité ambiante naturelle et des contributions naturelles de l'Atlantique, lesquelles varient elles aussi;
- le délai qui sépare la réduction des apports, de la baisse des teneurs elles-mêmes, est très long, surtout à cause de l'efficacité relative du cycle interne.

Although progress is being made in the development of 3-D models by modelling groups in most North Sea countries, the rate of progress is restricted by a number of obstacles. The most serious of these include difficulties in assessing the comparability of models, and in validating them against reality. A promising start to solving these problems was made at the NSTF Modelling Workshop (The Hague, 6–8 May 1992) where five different models were run, using whenever possible a common data set, to predict the effects of a 50% reduction in nutrient inputs on basic eutrophication variables. The results of the different models were consistent in direction and relative size of effects, with some exceptions. For the coastal region of the southern North Sea (NSTF Subregion 4), most of the models predicted a reduction of 16–24% in winter nutrient levels, with annual primary production decreasing by a similar proportion. Careful interpretation of these results is needed, however, as some models do not simulate important processes involved in nutrient dynamics or physical features such as coastal fronts and unusual circulation patterns, which must have an influence on nutrient reduction scenarios.

An important source of nitrogen for primary production is internal recycling within the water column. This mechanism appears to work at varying levels of efficiency in different areas of the southern North Sea. Thus nutrient recycling may act as a buffer in the sea to reductions in nutrient inputs.

It is possible to predict that the nutrient concentrations resulting from the 50% reduction scenario will still be elevated (a factor of 1.5 to 2 times higher) when compared with former known situations in some areas of the North Sea. If a 50% reduction in nitrogen inputs is not achieved, the resulting nitrogen concentrations will be even more elevated.

The resulting shift in the N/P ratio that could lead to phosphorus limitation in combination with an excess of nitrogen may also contribute to the production of toxic algal blooms.

Recommendations

General

A detailed assessment of measures taken to reduce the inputs of nutrients to the North Sea is still needed. It is expected that the goal of a 50% reduction in inputs of nitrogen to potential problem areas will not be realized by 1995, with the measures currently being taken or planned. In view of this, additional measures and better implementation and control to reduce nitrogen inputs must be considered. Given the indications that a further shift in the N/P ratio could increase current eutrophication problems, there is a need to seek a balanced reduction in nutrient inputs.

High priority should be given to achieving the goals set for nutrient reduction at the Second and Third International Conferences on the Protection of the North Sea. However, compared with background levels, it is expected that nutrient levels will still be elevated in certain areas even after a 50% reduction in inputs has been realized. Consequently, in 1995 the North Sea Ministers should consider the need to take decisions on the next steps in their strategy to reduce the eutrophication problems in the North Sea. These decisions should, *inter alia*, take into account:

- the input reductions realized and the use of existing national and international guidelines to reduce the

En dépit de l'ampleur des efforts consentis pour réduire les apports d'azote, l'on pense que les mesures que l'on prend en ce moment ou qui sont prévues ne permettront pas d'atteindre d'ici 1995 l'objectif global de 50% de réduction de ces apports aux zones oû ils sont susceptibles, directement ou indirectement, de donner lieu à une pollution. Cet état de choses est surtout dû au fait que les baisses probables dans le secteur agricole sont semble-t-il insuffisantes. En ce qui concerne le phosphore, la Belgique, le Danemark, l'Allemagne, les Pays-Bas, la Norvège et la Suède pensent pouvoir réduire les apports d'environ 50% entre 1985 et 1995.

Bien que les travaux de modélisation en 3 dimensions, effectués dans la plupart des pays de la mer du Nord, avancent, la progression de ces travaux se heurte à plusieurs obstacles, dont le plus important est qu'il est difficile d'apprécier la comparabilité des modèles, et de les valider par rapport à la réalité. Un début prometteur, dans le sens de la solution de ces problèmes, a été fait à l'atelier de modélisation du NSTF (La Haye, 6–8 mai 1992), où l'on a travaillé sur cinq modèles, en exploitant lorsque possible une série commune de données, afin de prévoir les conséquences qu'une baisse de 50% des apports de nutriments aurait sur les paramètres de base de l'eutrophisation. A quelques exceptions près, les résultats des divers modèles se sont avérés coïncider, aussi bien sur le plan de l'orientation que sur l'ampleur relative des effets. En ce qui concerne la région côtière du sud de la mer du Nord (sous-région 4 du NSTF), la plupart des modèles prévoient une baisse de 16 à 24% des teneurs en nutriments pendant l'hiver, la production primaire annuelle baissant dans une proportion analogue. Toutefois, il convient d'être prudent dans l'interprétation de ces résultats, car certains des modèles sont incapables de simuler d'importants processus de la dynamique des nutriments ou de simuler certaines des caractéristiques physiques, telles que les fronts côtiers et les profils anormaux de circulation, qui ne peuvent manquer d'avoir une influence sur les scénarios de réduction des nutriments.

Dans la production primaire, le recyclage qui intervient à l'intérieur même de la colonne d'eau est une importante source d'azote. L'efficacité de ce mécanisme semble varier selon les zones méridionales de la mer du Nord. Ainsi, en mer, le recyclage des nutriments pourrait jouer un rôle-tampon quant aux réductions des apports de nutriments.

L'on peut prédire que les teneurs en nutriments, qui résulteront du scénario de réduction de 50%, resteront fortes (coefficient de 1,5 à 2 fois plus) par rapport aux situations que l'on connaissait autrefois dans certaines zones de la mer du Nord. En outre, si l'on ne parvient pas à réduire de 50% les apports d'azote, les teneurs en azote qui en résulteront seront encore plus fortes.

La modification du ratio N/P qui en résultera, et qui risquerait de limiter les teneurs en phosphore tout en autorisant un excédent d'azote, a aussi des chances de contribuer à l'apparition d'éclosions d'algues toxiques.

Recommandations

Généralités

Une appréciation détaillée des mesures prises afin de réduire les apports de nutriments à la mer du Nord reste nécessaire. Il est probable que l'objectif de réduction de 50% des apports d'azote aux zones à problème potentiel ne sera pas réalisé d'ici 1995, ceci compte tenu des mesures que l'on prend à l'heure actuelle, ou qui sont prévues. Vu cet état de choses, il est impératif d'envisager des mesures complémentaires et une meilleure mise en oeuvre des mesures et des contrôles, visant à réduire les apports d'azote. Puisque l'on peut supposer qu'une nouvelle modification du ratio N/P risque d'accentuer les problèmes actuels d'eutrophisation, il convient de rechercher une réduction équilibrée des apports de nutriments.

Il est important d'accorder une haute priorité à ce que les objectifs de réduction en matière de nutriments, convenus à la

input to problem areas of nutrients from agriculture and forestry;
- the implementation of the common European agricultural policy and, particularly, of its extensification aspects;
- the observed change of the eutrophication status in problem areas (including impact on species composition and productivity of higher trophic levels);
- the ratio between phosphorus and nitrogen inputs and the possible impact of a shift in this ratio on the occurrence of toxic algal blooms and other effects (e.g., algal composition);
- other anticipated benefits.

Research

Reliable data on eutrophication are still required. They should include phytoplankton time series in the open sea to supplement land-based surveys and a better quantification of nutrient budgets and production, recycling, and circulation processes. Research should be intensified in order to improve risk assessment capability.

Further studies are also needed on plankton to determine any shift in species composition in the plankton community and at other trophic levels.

In future, assessments for estuaries which take into account local dynamics and fluxes should be used to provide calculated input budgets to the North Sea that can serve as a basis for control policies. The contribution of atmospheric inputs of nitrogen should also be investigated in greater detail with a view to identifying possible options for further reductions.

7.5.

Radioactivity

Issues of concern

Man-made radionuclides are clearly detectable in the marine environment, although this occurs against the considerable background of natural radioactivity, with man's exposure to radiation from artificial radionuclides being less, by two orders of magnitude, than that from natural radionuclides. In terms of public exposure, only caesium-137 is significant, and levels in the North Sea have declined about tenfold since 1984. The most significant natural radionuclide introduced by anthropogenic activity is polonium-210, and elevated levels have occurred in some localities from the phosphate-ore processing industry.

Taken overall, cause for concern appears to be decreasing, but this depends upon monitoring the current patterns of control for reducing exposure.

Agreed measures

Since 1985, the Paris Commission has examined on an annual basis statistical information about discharges from nuclear installations in the Convention area. This information, which covers nuclear power stations, reprocessing plants, fuel fabrication plants, and research and development facilities, is published in the Annual Reports of the Paris Commission.

The Paris Commission has adopted a number of measures relating to nuclear installations. The fol-

deuxième et la troisième Conférences internationales sur la protection de la mer du Nord, soient atteints. Toutefois, par rapport aux teneurs ambiantes, il est probable que les teneurs en nutriments resteront fortes dans certaines zones, même après que l'on aura réussi à réduire les apports de 50%. C'est pourquoi, en 1995, les Ministres de la mer du Nord devraient envisager de décider des prochaines étapes de leur stratégie de lutte contre les problèmes d'eutrophisation en mer du Nord. Ces décisions pourraient tenir compte, entre autres, des éléments suivants:

- réduction obtenue dans les apports, et application des lignes directrices nationales et internationales actuelles afin de réduire les apports de nutriments d'origine agricole et sylvicole aux zones à problèmes;
- mise en oeuvre de la politique agricole commune européenne, et plus particulièrement des mesures qu'elle prévoit en matière d'extensification;
- évolution de l'état de l'eutrophisation, telle qu'observée dans les zones à problèmes (dont son impact sur la composition des espèces et sur la productivité aux niveaux trophiques supérieurs);
- ratio entre apports de phosphore et apports d'azote, et impact éventuel de l'évolution de ce ratio sur l'apparition des éclosions d'algues toxiques et autres phénomènes (par exemple, sur la composition des populations d'algues);
- autres bienfaits anticipés.

Recherche

Des données fiables sur l'eutrophisation restent nécessaires. Il s'agit entre autres de séries chronologiques sur le phytoplancton en haute mer, qui viendraient compléter les études faites sur la côte, ainsi que d'une amélioration de la quantification des bilans et de la production, du recyclage et des processus de circulation des nutriments. Il conviendrait d'intensifier la recherche afin de développer les possibilités d'évaluation des risques.

D'autres études sont par ailleurs nécessaires sur le plancton, afin de déceler toute évolution de la composition des espèces au sein de la communauté planctonique, ainsi qu'à d'autres niveaux trophiques.

Dans l'avenir, pour calculer les bilans des apports à la mer du Nord, bilans pouvant servir de base aux politiques de lutte, il conviendrait de procéder, dans les estuaires, à des évaluations qui tiennent compte de la dynamique et des flux locaux. Par ailleurs, il conviendrait d'approfondir l'étude de la contribution des apports atmosphériques d'azote, afin d'élargir le spectre des options qui permettraient éventuellement de réduire plus encore les apports.

7.5.

Radioactivité

Problèmes préoccupants

Les radionucléides de synthèse sont aisément décelables dans le milieu marin, en dépit de la radioactivité naturelle ambiante considérable, l'exposition de l'homme au rayonnement des radionucléides artificiels étant inférieure, de deux ordres de grandeur, à son exposition aux radionucléides naturels. Sur le plan de l'exposition de la population, seul le caesium-137 est important, et ses teneurs en mer du Nord ont été divisées par dix à peu près depuis 1984. Le radionucléide naturel le plus important, dont la présence soit due aux activités de l'homme, est le polonium-210, de fortes teneurs ayant été constatées à certains endroits du fait de la présence d'industries de transformation du minerai de phosphate.

Globalement donc, les motifs d'inquiétude semblent s'éloigner, ceci dépendant toutefois des résultats des contrôles qui visent à réduire l'exposition.

lowing recommendations are currently in force (some have superseded previous recommendations which are not mentioned here):

a) *PARCOM Recommendation 91/4 on Radioactive Discharges*
This recommendation requires Contracting Parties 'to respect the relevant recommendations of the competent international organisations and to apply best available technology (BAT), as described further in PARCOM Recommendation 89/2, to minimise and, as appropriate, eliminate any pollution caused by radioactive discharges from all nuclear industries, including research reactors and reprocessing plants, into the marine environment'. It also requires Contracting Parties to present a progress report about the application of BAT to the Commission every four years.

b) *PARCOM Recommendation 93/5 Concerning Increases in Radioactive Discharges from Nuclear Reprocessing Plants*
Following a recommendation adopted in 1988, which required Contracting Parties to carry out an environmental impact assessment before constructing new nuclear reprocessing plants or before substantially increasing the capacity of existing installations, the Paris Commission adopted this recommendation in 1993. Contracting Parties agreed that 'a new or revised discharge authorisation for radioactive discharges from nuclear reprocessing installations should only be issued by national authorities if special consideration is given to 1) information on the need for spent nuclear reprocessing and on other options; 2) a full environmental impact assessment; 3) the demonstration that the planned discharges are based upon use of the best available techniques and observation of the Precautionary Principle; 4) a consultation with the Paris Commission on (1), (2) and (3).'

c) *PARCOM Recommendation 91/5 on the Disposal of Radioactive Wastes into Sub-Seabed Repositories Accessed from Land*
Contracting Parties agreed that the disposal of radioactive waste in repositories constructed in bedrock under the seabed and accessed from land constitutes a potential land-based source of marine pollution and that, therefore, the Paris Commission has the competence to consider such developments.

Effects of measures taken

The decrease noted in the concentrations of radionuclides in the North Sea is encouraging, and further decreases may be recorded in view of the current policy.

Recommendations

Research

There is a need to investigate the release of polonium-210 from the discharge of phosphogypsum wherever such discharges have occurred in the recent past.

Assessment tools

Data collection and modelling are necessary in order to keep under review the important radionuclides, and their pathways and processes, which contribute to doses to the public and marine organisms.

Mesures convenues

Depuis 1985, la Commission de Paris a étudié tous les ans les statistiques de rejet des installations nucléaires dans la zone de la Convention. Cette information, qui englobe les centrales nucléaires, les usines de retraitement, les installations de fabrication de combustible, ainsi que les laboratoires de recherche et de développement, est publiée dans les rapports annuels de la Commission de Paris.

La Commission de Paris a adopté plusieurs mesures touchant les installations nucléaires. Les recommandations ci-après sont en vigueur à l'heure actuelle (certaines d'entre elles ayant annulé et remplacé des recommandations antérieures, lesquelles ne sont pas évoquées ici):

a) *Recommandation PARCOM 91/4 sur les rejets radioactifs*
Cette recommandation porte que les Parties contractantes doivent «respecter les recommandations correspondantes des organisations internationales compétentes, et mettre en oeuvre la meilleure technologie disponible (BAT), telle que décrite plus avant dans la Recommandation PARCOM 89/2, afin de minimiser et, le cas échéant, de supprimer toute pollution provoquée par les rejets radioactifs, dans le milieu marin, de l'ensemble des industries nucléaires, y compris par les réacteurs de recherche et les usines de retraitement». Elle porte aussi que les Parties contractantes doivent présenter à la Commission, tous les quatre ans, un rapport d'avancement de la mise en oeuvre de la BAT.

b) *Recommandation PARCOM 93/5 relative à l'augmentation des rejets radioactifs des usines de retraitement des combustibles nucléaires*
Après la recommandation adoptée en 1988, qui prévoyait que les Parties contractantes procéderaient à une évaluation d'impact environnemental avant de construire de nouvelles installations de retraitement nucléaire, ou avant d'augmenter dans de fortes proportions la capacité des installations existantes, la Commission de Paris a adopté cette recommandation en 1993. Les Parties contractantes sont convenues que «aucun permis nouveau ou remanié de rejet radioactif des usines de retraitement nucléaire ne devait être émis par les autorités nationales avant que l'on ait étudié 1) les éléments d'information sur la nécessité du retraitement du combustible nucléaire usé ainsi que sur les autres options; 2) qu'une évaluation d'impact environnemental complète ait été effectuée; 3) que la preuve soit faite que les rejets prévus sont basés sur les meilleures techniques disponibles et sur le respect du principe de l'action de précaution; 4) que la Commission de Paris ait été consultée sur les points (1), (2) et (3).»

c) *Recommandation PARCOM 91/5 sur l'élimination des rejets radioactifs dans des dépôts creusés dans le sous-sol marin et accessibles depuis la terre*
Les Parties contractantes sont convenues que l'élimination des déchets radioactifs dans des dépôts creusés dans la roche du sous-sol marin, accessibles depuis la terre, constituait une source tellurique de pollution de la mer, et qu'en conséquence, la Commission de Paris disposait de la compétence qui lui était nécessaire afin de considérer cet état de choses.

Effets des mesures prises

La baisse que l'on a remarquée dans les teneurs en radionucléides en mer du Nord est encourageante, et compte tenu de la politique actuelle, il se peut que l'on enregistre de nouvelles diminutions dans ce domaine.

Recommandations

Généralités

Il convient d'étudier les émissions de polonium-210 dues aux rejets de phosphogypse dans les cas où ces rejets seraient récents.

7.6.

Litter

Issues of concern

Litter (including packing material, lost fishing gear, raw plastic pellets) is widespread in the North Sea. Birds and marine mammals are often entangled and drowned in lost fishing gear, and birds can also be affected when they ingest small plastic particles.

Agreed measures

On 18 February 1991 the North Sea was declared a 'Special Area' under Annex V (garbage) of MARPOL 73/78. Since this date the disposal of garbage in the North Sea by ships has been almost completely prohibited.

Effects of measures taken

Disposal from ships continues to occur and, together with leisure activities on beaches, remains a major source of litter. Rivers and sewage discharges also make a significant contribution. Plastics constitute most of the material.

Recommendations

Given the commitments on further control of litter disposal from ships and leisure craft, it is necessary to assess the impact of such controls through increased surveillance, and to improve the access to reception facilities in harbours.

7.7.

Microbiological pollution

Issues of concern

The quality of bathing water is a matter of concern along the shoreline of the North Sea.

Bathing or recreational water contaminated by microbiological or bacteriological pollution from insufficiently treated sewage is a well-recognized problem. The bacteriological quality of bivalve shellfish is of primary importance, and poor quality may lead to harvesting prohibitions in certain areas. The health of the marine environment away from the coast is not considered to be affected by this type of pollution.

Agreed measures

EEC Member States bordering the North Sea are bound by EEC Directive 76/160/EEC relating to the quality of bathing water. The directive regulates sampling and analytical procedures but, in practice, each EEC Member State has a sampling and analytical strategy that it considers most suitable for the practical implementation of the directive, which allows a wide range of interpretation.

In the EEC, shellfish quality is regulated by EEC Directive 91/492/EEC, which lays down the health conditions for the production and the placing on the market of live bivalve molluscs.

Outils d'évaluation

Pour poursuivre l'étude des radionucléides importants, des voies qu'ils empruntent et de leurs processus, lesquels contribuent à l'exposition du grand public et des organismes marins, il est nécessaire de collationner des données et de procéder à une modélisation.

7.6.

Ordures

Problèmes préoccupants

Les ordures (dont les emballages vides, les apparaux de pêche perdus en mer, les granulés de matière plastique non transformée) sont très répandues en mer du Nord. Les oiseaux et les mammifères marins sont souvent piégés par les apparaux de pêche ainsi perdus, et se noient de cette manière, tandis que les oiseaux qui ingèrent des granulés de matière plastique peuvent en subir les conséquences.

Mesures convenues

Le 18 février 1991, la mer du Nord a été déclarée «zone spéciale» dans le sens de l'Annexe V (ordures) de la Convention MARPOL 73/78. Depuis cette date, l'élimination des ordures en mer du Nord par les navires fait l'objet d'une interdiction quasi totale.

Effets des mesures prises

Les navires n'ont pas cessé de jeter leurs ordures en mer, et, parallèlement aux activités de loisirs sur les plages, ils demeurent une importante source à cet égard. Par ailleurs, les cours d'eau et les égouts sont aussi d'importantes sources d'apport. Ces ordures sont pour une grande part constituées de matières plastiques.

Recommandations

Compte tenu des engagements contractés à l'égard du renforcement des contrôles exercés sur l'élimination des ordures par les navires et par les embarcations de plaisance, il convient de juger des conséquences de ces contrôles, ceci en accentuant la surveillance, et en améliorant l'accès aux installations de réception dans les ports.

7.7.

Pollution microbiologique

Problèmes préoccupants

Le long du littoral de la mer du Nord, la qualité des eaux de baignade pose un problème préoccupant. La contamination microbiologique ou bactériologique des eaux de baignade ou de récréation, par les apports d'eaux usées insuffisamment traitées, est un problème bien connu. La qualité bactériologique des bivalves est d'une importance cruciale, des teneurs élevées en bactéries étant susceptibles de conduire à l'interdiction des récoltes dans certaines zones. L'on considère que le milieu marin au large des côtes n'est pas touché par ce genre de pollution.

Mesures convenues

Les Etats membres de la CEE côtiers de la mer du Nord sont liés par la Directive 76/160/CEE, qui a trait à la qualité des

Effects of measures taken

Assessments of the bacteriological status of North Sea bathing zones, and comparisons of status over time, have been difficult to make because different methodologies are employed by each country.

Recommendations

General

Poor bathing-water quality and poor shellfish quality present real human health risks that can only be avoided either by keeping away from the contaminated areas or, where the shellfish are only lightly contaminated, by subjecting them to approved purification techniques. The quality of bathing water can be adversely affected by discharges from inadequately treated sewage and from agricultural areas or storm water run-off. This indicates a need for additional policy measures. All waste water should be treated in such a way that environmental objectives concerning the quality of bathing water and of mariculture products are met. Diffuse sources of pollution should be addressed in similar terms.

Research

The Commission of the European Communities (CEC) has initiated an intercalibration exercise for microbiological determination and quantification methods from 1991 to 1993. Following the successful completion of this exercise, an attempt ought to be made to carry out a holistic assessment of the bacteriological status of North Sea coastal water.

7.8.

Fisheries and mariculture

Issues of concern

The main concern about sea fisheries was identified as their impact on commercial fish stocks and their possible contribution to the decline of some non-commercial fish stocks. As an effect of the generally high level of fishing effort, the mortality of non-target species may lead to a depletion of their stocks, e.g., sharks and rays. Changes in the genetic composition of fish populations, effects on benthic ecosystems (animals and plants), and effects on marine mammals and seabirds were also identified as matters of concern.

Long-term effects of fishing activities in the North Sea induce a shift in the age composition of larger, longer-lived fish species. Short-lived species are also favoured. No recent changes in this trend have been observed.

The mortalities of birds and mammals entangled in fishing gear have not yet been accurately quantified. There are no indications of any changes in numbers due to this effect.

There is concern that mariculture may affect the genetic composition of wild stocks, and there is evidence that it may introduce diseases and parasites from cultured stocks to wild stocks.

Agreed measures

At the Third International Conference on the Protection of the North Sea, Ministers agreed to

eaux de baignade. Cette directive réglemente les méthodes d'échantillonnage et d'analyse, quoique, dans la réalité, chacun des Etats membres de la CEE ait sa propre stratégie d'échantillonnage et d'analyse, qu'il considère comme la mieux adaptée à la mise en oeuvre de la directive, ce qui donne lieu à un large spectre d'interprétations.

Dans la CEE, la qualité des crustacés et des mollusques est réglementée par la Directive 91/492/CEE, qui fait état des conditions d'hygiène de la production et de la commercialisation des mollusques bivalves vivants.

Effets des mesures prises

Du fait de la diversité des méthodologies appliquées par chacun des pays, il s'est avéré difficile de juger de la bactériologie des zones de baignade de la mer du Nord, et de comparer les situations dans le temps.

Recommandations

Généralités

La mauvaise qualité des eaux de baignade, ainsi que celles des crustacés et des mollusques, présentent des risques très réels pour la santé de l'homme, que l'on ne peut éviter qu'en ce tenant à l'écart des zones contaminées ou, lorsque les crustacés et les mollusques ne sont que légèrement contaminés, en les soumettant à des techniques de purification approuvées à cet effet. Les rejets d'eaux usées insuffisamment traitées, ainsi que les eaux de ruissellement des zones agricoles et les eaux de pluie, peuvent avoir une influence préjudiciable sur la qualité des eaux de baignade. Il est donc nécessaire de prendre des mesures politiques complémentaires. Il conviendrait de traiter la totalité des eaux usées dans des conditions telles que les objectifs environnementaux de qualité des eaux de baignade ainsi que ceux des produits de la mariculture, soient réalisés. Les sources diffuses de pollution devraient être attaquées dans des conditions analogues.

Recherche

La Commission des communautés européennes (CCE) a fait faire une campagne d'interétalonnage des méthodes d'analyse microbiologique et des méthodes de quantification microbiologique, laquelle d'est déroulée de 1991 à 1993. Cette campagne ayant abouti, il convient de s'efforcer de procéder à une évaluation exhaustive de la bactériologie des eaux côtières de la mer du Nord.

7.8.

Pêche et mariculture

Problèmes préoccupants

La principale préoccupation suscitée par les pêcheries en mer tient à leur impact sur les stocks de poissons commerciaux et sur la part qu'elles ont peut-être dans la baisse des stocks de poissons non commerciaux. Du fait, d'une façon générale, de l'ampleur même des captures, le sacrifice des espèces non ciblées par la pêche peut aboutir à un épuisement de leurs stocks, par exemple dans le cas des requins et des raies. Parmi les problèmes préoccupants, l'on a aussi évoqué la modification de la composition génétique des populations halieutiques, les effets sur les écosystèmes benthiques (animaux et végétaux), ainsi que les effets sur les mammifères marins et les oiseaux de mer.

A long terme, la pêche en mer du Nord entraîne une évolution de la structure d'âge des gros poissons à vie longue. Par ailleurs, ce sont les espèces à vie courte qui sont favorisées. Aucune évolution de cette tendance n'a été observée.

consider both the impact of fisheries (including fish farming) on the North Sea ecosystem and the impact of the marine environment on fisheries resources, also in relation to the socio-economic value of fisheries. The Ministers agreed to continue their efforts aimed at ensuring that fishing activities and the level of fishing effort in the North Sea are compatible with maintaining the fish stocks as a renewable resource at a satisfactory level and avoiding destabilization of the ecosystem.

In the EEC, fisheries are an exclusive Community competence. Regulation 3760/92/EEC established a Community system for fisheries and aquaculture. According to the new basic regulation, the objective should be to provide for rational and responsible exploitation of living aquatic resources and of aquaculture, while recognizing the interest of the fisheries sector in its long-term development and its economic and social conditions, and the interest of consumers, taking into account the biological constraints and with due respect for the marine ecosystem. The selectivity of fishing methods should be improved with a view to optimal utilization of biological potential and the limitation of discards, for the purposes of rational and responsible exploitation of resources. Under the regulation, the Council of Ministers is establishing measures in order to ensure the rational and responsible exploitation of resources on a sustainable basis.

Fisheries agreements have been developed, and annual meetings, benefiting from ICES advice, permit bilateral agreements to be made on total allowable catch and technical measures. Aquaculture is covered by a variety of regulations. Projects receiving Community funds are subject to an assessment of their effects on the environment under EEC Directive 85/337/EEC.

At the Sixth Trilateral Governmental Wadden Sea Conference (1991), Ministers recognized the negative ecological effects of the cockle and mussel fisheries in the Wadden Sea and agreed to close a considerable part of the area to these activities. Furthermore, concern was expressed about the incidental by-catch of marine mammals in fishing gear.

Effects of measures taken

Fishing mortality rates are generally too high on most commercial fish species in the North Sea. No firm conclusions can be drawn about the impact of fishing on non-commercial species. The available time series show changes in abundance for most species, but the extent to which these changes can be attributed to fishing is unknown.

On a local scale, physical effects of fishing activities on benthos have been documented. The evidence for widespread and general effects is unclear, and the extent to which changes have occurred cannot be assessed.

In case studies, it has been shown that a high proportion of discards can be taken by birds. For some bird species, an increase in numbers has been attributed to the availability of this food, but decreases in hunting pressure on some of them may also be involved. Other bird species have decreased in numbers, which may be attributable to competition for the same

Le nombre d'oiseaux et de mammifères morts parce que pris dans les apparaux de pêche n'a pas encore été quantifié avec précision. Rien n'indique cependant une quelconque évolution du nombre d'animaux morts de ce fait.

On s'inquiète par ailleurs que la mariculture puisse influer sur la composition génétique des stocks d'organismes sauvages, certains indices donnant à penser que la mariculture est à l'origine de la transmission, par les stocks d'animaux cultivés aux stocks d'animaux sauvages, de maladies et de parasites.

Mesures convenues

A la troisième Conférence internationale sur la protection de la mer du Nord, les Ministres sont convenus de considérer aussi bien l'impact de la pêche (dont la pisciculture) sur l'écosystème de la mer du Nord, que l'impact du milieu marin sur les ressources des pêcheries, tenant compte de la valeur socio-économique des pêcheries. Les Ministres sont convenus de poursuivre les efforts qui visent à faire en sorte que les activités de pêche et l'ampleur des captures en mer du Nord soient compatibles avec la conservation des stocks halieutiques, ressources devant se renouveler dans des proportions adéquates, sans déstabilisation de l'écosystème.

Au sein de la CEE, la pêche est de la compétence exclusive de la Communauté. La Réglementation 3760/92/CEE porte création d'un système communautaire de pêche et d'aquaculture. Selon la nouvelle réglementation cadre, l'objectif doit être d'assurer une exploitation rationnelle et intelligente des ressources aquatiques vivantes et de l'aquaculture, tout en tenant compte des intérêts du secteur de la pêche et son évolution à long terme ainsi que l'économie et l'état social du secteur, ainsi que de l'intérêt des consommateurs, les contraintes biologiques devant être prises en compte, l'écosystème marin devant en outre être protégé. Il conviendrait d'améliorer la sélectivité des méthodes de pêche, afin d'optimiser l'exploitation du potentiel biologique et de limiter les restitutions à la mer, l'exploitation des ressources devant se faire dans des conditions rationnelles et intelligentes. Dans le cadre de cette réglementation, le Conseil des Ministres met sur pied des mesures devant assurer une exploitation rationnelle et intelligente des ressources, et ceci dans des conditions soutenables.

Des accords ont été conclus dans le domaine de la pêche, les réunions annuelles, qui bénéficient des conseils du CIEM, permettant de conclure des accords bilatéraux sur les quotas de capture tolérable ainsi que sur des mesures techniques. L'aquaculture fait l'objet de toute une série de réglementations. Les conséquences que les projets financés par la Communauté ont sur l'environnement font l'objet d'une appréciation en vertu de la Directive 85/337/CEE.

A la sixième Conférence gouvernementale trilatérale sur la mer des Wadden (1991), les Ministres ont reconnu le préjudice écologique causé par les pêcheries de coques et de moules de la mer des Wadden, et sont convenus d'interdire ces activités dans une proportion considérable de cette zone. De plus, des inquiétudes ont été exprimées sur les captures fortuites de mammifères marins dans les apparaux de pêche.

Effets des mesures prises

Pour la plupart des espèces commerciales de poisson de la mer du Nord, les taux de mortalité dûs à la pêche sont en général trop élevés. Aucune conclusion définitive ne peut être tirée sur l'impact que la pêche a sur les espèces non commerciales. Les séries chronologiques en possession mettent en évidence un changement de l'abondance de la plupart des espèces, la mesure dans laquelle ce changement peut effectivement être attribuée à la pêche restant toutefois inconnue.

prey. Changes in distribution also appear to be associated with changes in the abundance and distribution of the prey. However, there is no evidence that changes in the prey have been caused by fisheries. The effect of recent changes in policy cannot yet be assessed.

Recommendations

General

Policies for sea fisheries should be directed towards stimulating a sustainable situation with respect to the ecosystem of the North Sea as a whole. Some countries have recently decided to adopt such an approach.

To implement the above objective and to reduce the effects described, North Sea countries could undertake concerted action to reach agreement on the following measures, taking into account the biological constraints and with due respect for the marine ecosystem:

1) *Measures to reduce fisheries impact*
- to reduce the general level of fishing to a more sustainable level;
- to reduce the by-catch of non-target fish by technical measures (closed season and closed areas, technical improvements to enhance the selectivity of fishing gear) and by changes in the system of Total Allowable Catches (TACs) and quotas; consideration should be given to the introduction of multi-species TACs in the management of commercial fisheries;
- to reduce, as a matter of urgency, fishing effort on those species (e.g., North Sea stocks of cod and haddock) which are now exploited at levels that are considered to be in excess of sustainable levels;

2) *Investigations to develop future management tools*
- to establish undisturbed areas in the North Sea for scientific purposes in order to investigate the recovery and redevelopment of the marine ecosystem, particularly in the absence of fishing activities.

Research

Information is needed on short-lived fish species exploited by the industrial fisheries. The impact of fishing activities on non-commercial species of fish should also be assessed.

A better understanding of recruitment of benthic species in areas disturbed by fishing gear is required. General information on the population dynamics of birds and mammals in relation to fishing activities should be collected, and there is a need to improve the knowledge of interrelationships between species and their environment. Fisheries should be viewed as one component of a whole ecosystem.

The need for scientific advice based on ecosystem models (or at least broad considerations) is at present being discussed. As scientific advice on ecosystem management becomes more available, it can form the basis for improved environmentally oriented fisheries management. This also applies to mariculture, where efforts should be made to integrate its development into coastal zone management plans.

Proposals should be developed to reduce the negative effects of beam trawling on benthic life. Undisturbed reference sites are not available, and the establishment of areas closed to fishing for purposes of scientific investigation would facilitate an understanding of the processes.

A l'échelon local, l'on est bien renseigné sur les effets physiques que la pêche a sur le benthos. L'on connaît en revanche mal les phénomènes très répandus de même que les effets généraux, la mesure dans laquelle cette évolution est bien réelle ne pouvant toutefois être appréciée.

Il a été démontré, par des études de cas, qu'une forte proportion des captures restituées à la mer pouvait être consommée par les oiseaux. Dans le cas de certaines espèces d'oiseaux, l'augmentation du nombre d'oiseaux a été attribué à la présence de cette nourriture, quoique la baisse de la chasse de certaines de ces espèces puisse aussi avoir joué un rôle. Les colonies d'autres espèces d'oiseaux ont diminué, phénomène peut-être imputable à la concurrence qui s'exerce dans la capture des mêmes proies. Le changement de la distribution paraît par ailleurs associée au changement de l'abondance et de la distribution des proies. Toutefois, rien ne prouve que l'évolution des proies ait été provoquée par la pêche. Les conséquences des récentes réformes politiques ne peuvent encore être appréciées.

Recommandations

Généralités

La politique de la pêche en mer devrait être orientée sur la création d'une situation soutenable pour l'écosystème de l'ensemble de la mer du Nord. Certains pays ont récemment décidé d'adopter cette stratégie.

Pour pouvoir réaliser l'objectif ci-dessus, et atténuer les phénomènes évoqués, les pays de la mer du Nord pourraient se concerter et se mettre d'accord sur les mesures ci-après, en tenant compte des contraintes biologiques, et de l'écosystème marin:

1) *Mesures visant à atténuer l'impact de la pêche*
- ramener la pêche en général à un niveau plus tolérable;
- réduire les captures fortuites de poisson non ciblé par la pêche, ceci grâce à des mesures techniques (saison fermeture de la pêche, et zones fermées à la pêche, perfectionnements techniques devant renforcer la sélectivité des apparaux de pêche), ainsi que grâce à une réforme du système dit du «total des captures autorisées» et des quotas; dans la gestion des pêcheries commerciales, l'on pourrait envisager un système de «total des captures autorisées» sur plusieurs espèces, dans la gestion des pêcheries commerciales;
- réduire d'urgence l'ampleur des opérations de pêche des espèces (par exemple, les stocks de morues et d'aiglefins de la mer du Nord), espèces dont l'exploitation actuelle est considérée comme supérieure aux niveaux soutenables;

2) *Investigations visant à développer de futurs outils de gestion*
- créer des zones intactes en mer du Nord, à des fins scientifiques, pour pouvoir étudier la récupération et le nouvel essor de l'écosystème marin, en particulier en l'absence d'opérations de pêche.

Recherche

Des informations sont nécessaires sur les espèces de poisson à vie courte exploités par les pêcheries industrielles. L'on pourrait par ailleurs évaluer l'impact des opérations de pêche sur les espèces de poisson non commerciales.

Une meilleure compréhension du recrutement des espèces benthiques dans les zones troublées par les apparaux de pêche est nécessaire. Il conviendrait de recueillir des éléments d'information d'ordre général sur la dynamique des populations d'oiseaux et de mammifères, en fonction des opérations de pêche, tandis qu'il est par ailleurs nécessaire de développer la connaissance que l'on a des relations entre les espèces et leur environnement. Les pêcheries devraient être considérées comme l'une des composantes de l'ensemble de l'écosystème.

L'on débat à l'heure actuelle des conseils scientifiques issus des modèles de l'écosystème qu'il conviendrait de se procurer

There is a need to investigate the occurrence of incidental by-catches of marine mammals and birds in fishing gear and to introduce measures based on these investigations.

7.9.

Species and habitats

Issues of concern

Pollution is only one of the problems (albeit a significant one) threatening the viability of the North Sea as an ecosystem. The alteration and destruction of marine and coastal habitats through improper development practices and poor planning are also significant problems.

Man's interference with the North Sea increases as one moves south. Engineering works have resulted in the loss of habitats along the coastline. The intertidal environment, and salt marshes in particular, have been reduced in size. A decrease in the numbers of certain species has been attributed to the loss of nursery grounds.

Agreed measures

Habitat conservation is receiving increasing attention as an important aspect of wildlife protection as well as of ecosystem management.

The protection of varied types of habitats is of fundamental importance both to the maintenance of species biodiversity and to ecosystem management in general. For nature and wildlife protection, the most important EEC legislation until recently has been the 1979 Wild Birds EEC Directive 79/409/EEC, which includes provisions for Member States to set aside 'Special Protection Areas' (SPAs), tying the directive in with the provisions of the Ramsar Convention on Wetlands of International Importance, Especially as Waterfowl Habitat. More recently, a comprehensive, legally binding directive (92/43/EEC) on the protection of species and habitats has been adopted. The habitat provisions under this directive are in accord with the Agenda 21 Declaration from the United Nations Conference on Environment and Development (UNCED). Combined with the 1979 Bern Convention on the Conservation of European Wildlife and Natural Habitats and the Ramsar Convention, it will strengthen habitat and species protection in Europe. Within the framework of the LIFE (NORSPA) Programme of the European Economic Community, a project on marine conservation areas has been initiated. The project focuses primarily on coastal waters and, where appropriate, the Exclusive Economic Zone and the fisheries zone.

In response to threats facing small cetaceans and in view of the relative lack of knowledge about them in the North Sea, a Memorandum of Understanding on Small Cetaceans in the North Sea was signed at the Third International Conference on the Protection of the North Sea. In parallel, the three Wadden Sea States concluded the Wadden Sea Seals Agreement. The Memorandum stipulates the establishment of a framework for cooperation with

(ou à tout le moins des grandes considérations qui seraient nécessaires). Au fur et à mesure que sont mis au point les conseils scientifiques sur la gestion de l'écosystème, ces conseils permettraient d'améliorer la gestion écologique des pêcheries. Ceci est également vrai de la mariculture, qu'il conviendrait de tenter d'intégrer aux programmes de gestion des zones côtières.

Des propositions devraient être mises au point afin de combattre les effets négatifs du chalutage à perche sur la vie benthique. Il n'existe pas de zone de référence intacte, la création de telles zones fermées aux pêcheries, à des fins scientifiques, devant permettre de mieux comprendre les processus.

Il convient d'étudier la fréquence des captures accidentelles de mammifères marins et d'oiseaux de mer dans les apparaux de pêche, et d'adopter des mesures fondées sur le résultat de ces études.

7.9.

Espèces et habitats

Problèmes préoccupants

La pollution n'est que l'un des problèmes (pour important qu'il soit) qui menacent la viabilité de l'écosystème de la mer du Nord. Le bouleversement et la destruction des habitats marins et côtiers par de mauvaises méthodes d'aménagement, et par des erreurs de planification, posent également d'importants problèmes.

L'intervention de l'homme en mer du Nord s'accentue tandis que l'on descend vers le sud. Les ouvrages construits sur le littoral ont fait disparaître certains habitats. La taille de la zone de marnage, et plus particulièrement des marais salants, a diminué. La baisse des effectifs de certaines espèces a été attribuée au rétrécissement des zones de frai.

Mesures convenues

La conservation des habitats est de plus en plus considérée comme un aspect important de la protection de la vie sauvage, ainsi que de la gestion des écosystèmes.

La protection d'habitats diversifiés est d'une importance fondamentale tant pour le maintien de la biodiversité des espèces que pour la gestion des écosystèmes en général. Aux fins de la protection de la nature et de la vie sauvage, jusqu'à une époque récente, la législation la plus importante de la CEE était la Directive 79/409/CEE de 1979, sur les oiseaux sauvages, qui porte que les Etats membres prendront des dispositions afin de créer des «zones de protection spéciales», qui établit un lien entre la Directive elle-même, et les dispositions de la Convention Ramsar sur les marécages d'importance internationale, et plus particulièrement en tant qu'habitats des oiseaux aquatiques. Plus récemment, une directive exhaustive (92/43/CEE) sur la protection des espèces et des habitats a été adoptée. Les dispositions qui, dans cette directive, ont trait aux habitats, coïncident avec le point 21 de la Déclaration issue de la Conférence des Nations Unies sur l'environnement et le développement (UNCED). Articulée avec la Convention de Berne (1979) sur la conservation de la vie sauvage et des habitats naturels européens, et avec la Convention Ramsar, elle renforcera la protection des habitats et des espèces en Europe. Par ailleurs, un programme a été amorcé pour les zones de conservation marines dans le cadre du Programme LIFE (NORSPA) de la Communauté économique européenne. Ce programme est surtout orienté sur les eaux côtières, et, le cas échéant, sur la zone économique exclusive et sur la zone de pêche.

Compte tenu des menaces qui pèsent sur les petits cétacés, et des lacunes relatives des connaissances sur les petits cétacés de la mer du Nord, un Mémorandum d'entente sur les pe-

Baltic Sea States in the form of an agreement, as referred to in Articles IV and V of the Convention on the Conservation of Migratory Species of Wild Animals (Bonn, 1979). It is intended to encourage cooperative research efforts on small cetaceans and thereby to arrive at an effective regime for their conservation.

Important innovations from the Third International Conference on the Protection of the North Sea include an acceptance of the concepts of an integrated ecosystems approach and sustainable development. The Declaration includes a recommendation to consider the impact of fisheries (including fish farming) on the North Sea ecosystem and the impact of the marine environment on fisheries resources, also in relation to the socio-economic value of fisheries, and reiterates its acceptance of the special importance of the Wadden Sea. The Wadden Sea States and English Nature (Nature Conservancy Council for England) recognize strong ecological links between the Wadden Sea and the Wash and have therefore signed a Memorandum of Intent to cooperate with a view to establishing comprehensive protection for a linked network of North Sea coastal areas. A regional agreement on the protection of small cetaceans between North Sea and Baltic Sea coastal states under the Convention on the Conservation of Migratory Species of Wild Animals has been signed by most North Sea States. In addition, an Annex on the Protection of Species and Habitats was agreed upon, containing specific requests to the North Sea Task Force to carry out further studies on these issues.

The Third International Conference on the Protection of the North Sea also requested the North Sea Task Force to elaborate techniques for the development of ecological objectives that should form a solid basis for the protection of the North Sea. Ecological objectives are being elaborated for the Wadden Sea in another forum as well.

Effects of measures taken

Seabird communities are subject to various environmental influences, but in general the relative effects of these influences are still not well understood. There is better understanding of marine mammal populations, although this is by no means complete. Sightings and strandings of marine mammals are being systematically recorded in several North Sea countries to improve knowledge of the current state of populations, their distribution, and their migratory patterns. Several projects on the causes of death of stranded cetaceans are providing information on their health and biology in the North Sea.

Recommendations

General

Individual species require particular habitats. Specific habitats can be of value because they represent an important or unique ecosystem within the wider context of the North Sea. Although the Third International Conference on the Protection of the North Sea has taken a first step towards protecting species and habitats, including calling attention to the need to identify marine sites of national or international importance, improving the quality of the North Sea requires that

tits cétacés de la mer du Nord a été signé à la troisième Conférence internationale sur la protection de la mer du Nord. Parallèlement, les trois Etats de la mer des Wadden concluaient l'Accord sur les phoques de la mer des Wadden. Le Mémorandum porte création d'un cadre de coopération avec les Etats de la mer Baltique, sous la forme d'un accord, visé aux Articles IV et V de la Convention sur la conservation des espèces migratoires d'animaux sauvages (Bonn, 1979). Il est prévu de développer les travaux de recherche en collaboration sur les petits cétacés, et par là même, de mettre sur pied un régime efficace qui permettra de les protéger.

La troisième Conférence internationale sur la protection de la mer du Nord a donné lieu à d'importantes innovations, dont l'acceptation des concepts d'approche intégrée des écosystèmes et de développement soutenable. La Déclaration contient une recommandation qui vise à étudier l'impact que la pêche (dont la pisciculture) a sur l'écosystème de la mer du Nord, ainsi que l'impact que le milieu marin a sur les ressources des pêcheries, en tenant compte de la valeur socio-économique des pêcheries, tout en réaffirmant l'importance particulière que revêt la mer des Wadden. Les Etats de la mer des Wadden et «English Nature» (Conseil anglais de la protection de la nature) sont conscients des liens écologiques étroits qui existent entre la mer des Wadden et le Wash, et ont de ce fait signé un Mémorandum d'intention de coopération, dont le but est d'assurer la protection complète de tout un réseau de zones côtières en mer du Nord. Un accord régional sur la protection des petits cétacés, passé entre les Etats côtiers de la mer du Nord et de la mer Baltique, en vertu de la Convention sur la conservation des espèces migratoires d'animaux sauvages, a été signé par la plupart des Etats de la mer du Nord. De plus, l'on s'est mis d'accord sur une annexe relative à la protection des espèces et des habitats, annexe qui demande spécifiquement au Groupe d'intervention mer du Nord de procéder à de nouvelles études dans ces domaines.

La troisième Conférence internationale sur la protection de la mer du Nord a par ailleurs demandé au Groupe d'intervention mer du Nord de mettre au point des techniques permettant de définir des objectifs écologiques qui constitueraient une base solide pour la protection de la mer du Nord. Une autre instance élabore par ailleurs des objectifs écologiques pour la mer des Wadden.

Effets des mesures prises

Les colonies d'oiseaux de mer subissent diverses influences environnementales, quoique, en général, les effets relatifs de ces influences ne soient pas encore bien appréhendés. On comprend mieux les populations de mammifères marins, en dépit du fait que même dans ce domaine, les connaissances ne soient pas complètes. Les observations et les échouages de mammifères marins sont systématiquement relevés dans plusieurs des pays de la mer du Nord, afin de mieux connaître l'état actuel des populations, leur distribution, et leurs profils de migration. Plusieurs programmes relatifs aux causes de la mort des cétacés échoués sur les côtes de la mer du Nord permettent de se procurer des informations sur leur état de santé et sur leur biologie.

Recommandations

Généralités

Toute espèce a besoin d'un habitat particulier. Ces habitats peuvent être précieux parce qu'ils constituent par eux-mêmes un écosystème important ou unique dans le contexte de l'ensemble de la mer du Nord. Bien que la troisième Conférence internationale sur la protection de la mer du Nord ait fait un premier pas dans le sens de la protection des espèces et des habitats, y compris en appelant l'attention sur le fait qu'il est important de défimore emphasis be given to species and habitat protection. As far as individual species are concerned, this is especially true for marine mammals, seabirds and coastal birds, and benthic and long-lived species. The North Sea (or parts of it) should be considered as habitats for these species.

Generally, coastal areas are habitats which have a special ecological significance for the North Sea. Many of these habitats are interlinked through ecological relationships and also play a role in the life cycle of a number of the species mentioned above.

The protection of species and habitats in the North Sea should not be based on a number of separate measures directed to the protection of certain species on the one hand and certain habitats on the other. The protection of species and habitats needs an integrated ecosystem approach, based on the conviction that an ecological network should be protected and restored where necessary.

It should also be realized that pollution reduction plays an important role. In this context, it is important to note that concentrations of hazardous substances are generally higher in coastal areas compared with open sea areas. In addition, many of the species mentioned above are top predators and, therefore, at the end of the process of accumulating hazardous substances in biota.

Measures

With reference to the general remarks above, the following is recommended:

- in the context of the protection of species and habitats, pollution reduction continues to deserve high priority.

In the further development of a strategy to protect species and habitats, the following policy options should be considered:

- to implement with high priority the provisions of the Declaration of the Third International Conference on the Protection of the North Sea concerning the protection of species and habitats, i.e., the identification of marine sites (including coastal, estuarine, and open sea areas) of national or international importance, in accordance with criteria to be adopted;
- to identify an ecological network of habitats in the North Sea which could serve as the focal point for the protection of selected species;
- to use the elements (species and habitats) of this network, and the identified marine sites of national or international importance, for the further elaboration of ecological objectives for the North Sea;
- to develop special protection regimes for these habitats (including coastal, estuarine, and open sea areas), *inter alia*, including measures to reduce particular sea uses and to establish water quality objectives;
- to establish programmes for the protection and/or recovery of selected species.

Research

Marine biodiversity is a matter of growing concern for the protection of species and habitats, but there is a basic need to define 'biodiversity' in terms of the marine environment.

nir des zones marines d'une importance nationale ou internationale, la nécessité même d'améliorer la qualité de la mer du Nord exige qu'une attention accrue soit accordée à la protection des espèces et des habitats. En ce qui concerne les espèces en cause, ceci est particulièrement vrai des mammifères marins, des oiseaux de mer et des oiseaux du littoral, ainsi que des espèces benthiques et des espèces à longue vie. La mer du Nord (ou des parties de celle-ci) devrait être vue comme l'habitat de ces espèces.

D'une façon générale, les zones côtières sont des habitats qui présentent une importance écologique particulière pour la mer du Nord. Il existe des rapports écologiques entre nombre de ces habitats, qui jouent par ailleurs un rôle dans le cycle de vie de plusieurs des espèces ci-dessus citées.

La protection des espèces et des habitats de la mer du Nord ne devrait pas être fondée sur une série de mesures distinctes les unes des autres, orientées sur la protection de certaines espèces d'une part, et de certains habitats d'autre part. La protection des espèces et des habitats exige une stratégie intégrée de protection des écosystèmes, fondée sur la conviction qu'un réseau écologique doit être protégé et rétabli lorsque nécessaire.

Il convient par ailleurs de se rendre compte que la réduction de la pollution joue un rôle majeur. Dans ce contexte, il est important de noter que les teneurs des substances dangereuses sont en général plus élevées dans les zones côtières qu'elles ne le sont en haute mer. De plus, nombre des espèces ci-dessus citées sont des prédateurs supérieurs, et par conséquent, se situent à l'extrémité du processus d'accumulation des substances dangereuses dans le biote.

Mesures

La recommandation ci-après découle des remarques ci-dessus:

- en ce qui concerne la protection des espèces et des habitats, la réduction de la pollution doit rester une haute priorité.

Dans la poursuite de l'élaboration d'une stratégie de protection des espèces et des habitats, il conviendrait d'envisager les options politiques ci-après:

- accorder une haute priorité à la mise en oeuvre des dispositions de la Déclaration issue de la troisième Conférence internationale sur la protection de la mer du Nord, dispositions relatives à la protection des espèces et des habitats, autrement dit, la définition de zones marines (dont des zones côtières, estuariennes et de haute mer) présentant une importance au plan national ou international, ceci selon des critères qui seraient adoptés à cet effet;
- définition d'un réseau écologique d'habitats en mer du Nord, qui pourrait servir de pivot à la protection des espèces sélectionnées;
- exploitation des éléments (espèces et habitats) de ce réseau, et des zones marines définies comme d'importance nationale ou internationale, afin de poursuivre l'élaboration de la définition des objectifs écologiques pour la mer du Nord;
- élaboration de régimes spéciaux de protection de ces habitats (dont les zones côtières, estuariennes et de haute mer), englobant, entre autres, des mesures visant à faire reculer telle ou telle utilisation de la mer, et à définir des objectifs de qualité de l'eau;
- mise sur pied de programmes de protection et/ou de rétablissement de certaines espèces choisies à cet effet.

Recherche

L'on considère que la biodiversité marine est de plus en plus importante pour la protection des espèces et des habitats; à la base, il reste toutefois à définir le terme «biodiversité» dans le contexte du milieu marin.

Monitoring habitats is necessary. The monitoring programme should be able to provide information that will be useful in guiding the restoration and protection of North Sea resources by maintaining long-term continuity.

Not enough is known about diet, food ecology, and the complex relationships between plankton, fish, birds, mammals, and the other components of the ecosystem.

Il faut surveiller les habitats. Il conviendrait que le programme de surveillance permette de se procurer des renseignements utiles à l'orientation du rétablissement et de la protection des ressources de la mer du Nord, ceci en maintenant une continuité à long terme.

L'on est insuffisamment renseigné sur le régime alimentaire, sur l'écologie de l'alimentation, et sur les rapports complexes qui existent entre le plancton, le poisson, les oiseaux, les mammifères, et les autres composantes de l'écosystème.