IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP
JOINT GROUP OF EXPERTS ON THE SCIENTIFIC ASPECTS
OF MARINE POLLUTION
- GESAMP -

REPORTS AND STUDIES

No. 15

The Review of the Health of
the Oceans

UNESCO United Nations Educational, Scientific and Cultural Organization

IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts
on the Scientific Aspects of Marine Pollution (GESAMP)

The Review of the Health of the Oceans

NOTE : **This report also appeared as UNEP Regional Seas
Reports and Studies No. 16**

Unesco, 1982

NOTES

1.   GESAMP is an advisory body consisting of specialized experts nominated by the Sponsoring Agencies (IMCO, FAO, UNESCO, WMO, WHO, IAEA, UN, UNEP). Its principal task is to provide scientific advice on marine pollution problems to the Sponsoring Agencies and to the Intergovernmental Oceanographic Commission ·(IOC).

2.   The report contains views expressed by experts acting in their.individual capacities which may not necessarily correspond with the views of the Sponsoring Agencies.

3.   Permission may be granted by any one of the Sponsoring Agencies for the report to be wholly or partly reproduced in publications, provided that the source of the extract and the condition mentioned in 3 above are indicated.

OTHER ISSUES IN THIS SERIES

PREFACE

Although the idea of summarizing the state of marine pollution in the world oceans is probably much older than one might imagine, the specific idea of reviewing the health of the oceans seems to have first arisen in the report of the ACMRR/SCORR/WMO Joint Working Party on Global Ocean Research (Ponza and Rome, 29 April - 7 May 1969).

This idea was taken up by the ACMRR/SCOR/ACOMR/GESAMP Joint Working Party on the Global Investigation of Pollution in the Marine Environment (San Marco di Castellabate and Rome, 11 - 18 October 1971).

The Action Plan adopted at the United Nations Conference on the Human Environment (Stockholm, 5 - 16 June 1972) recommended that GESAMP should assemble scientific data and provide advice on scientific aspects of marine pollution especially those of an interdisciplinary nature.

The IOC International Co-ordination Group for GIPME at its first session (London, 2 - 6 April 1973) recommended that the Secretary of IOC retain a consultant to bring together the available data into a report on the Health of the Oceans. Professor E. D. Goldberg of the University of California at San Diego was asked to do this work, and his report was published by UNESCO in 1976.

The fifteenth session of the Inter-Secretariat Committee on Scientific Programmes Relating to Oceanography (ICSPRO), recommended "....... that GESAMP should be invited to advise agencies, and UNEP was asked to take the initiative, in consultation with other agencies, for the preparation of a detailed request to GESAMP for a critical examination of present and planned methods by which to generate a continuous authoritative review and assessment of the health of the oceans". The initiative requested of UNEP was taken at the meeting of the GESAMP Joint Secretariat (Geneva, 4 - 5 June 1977) when it was decided that the preparation of "periodic reviews of the state of the marine environment as regards marine pollution" should become one of the main terms of reference for GESAMP.

The tenth session of GESAMP (Paris, 25 February - 1 March 1978) established the Working Group on a Review of the Health of the Oceans, with the objective of providing:

> "a periodically updated review of: the state of pollution of the world's oceans; the global mass balance of marine pollution; the trends of changes in ocean-related natural processes (e.g. climate) and living resources, amenities and other legitimate uses of the marine environment as well as on the land directly influenced by the oceans".

The Working Group was given the following terms of reference:

(i) to provide succinct periodic (3-4 years) critical reviews and scientific evaluation of the influence of pollutants on the marine environment;

(ii)   to advise on the extent to which potentially harmful substances, processes or activities may affect the health of the oceans and the various uses of the marine environment;

(iii) to advise on areas requiring further examination either because of their relatively higher degree of contamination or lack of detailed accurate information.

All GESAMP co-sponsors (IMCO, FAO, UNESCO, WMO, WHO, IAEA, United Nations and UNEP) expressed their wish to co-operate and provide inputs to the work of the Group. UNESCO was asked to be the Lead Agency, providing administrative and technical support for the Group, with major financial support provided by UNEP. The composition of the Working Group was carefully selected by the co-sponsors of GESAMP and the Chairman of the Group, taking into account the necessity of covering most scientific disciplines as well as having experts from as many regions of the world as possible.

At the first meeting of the Working Group, held in Copenhagen (5 - 11 July 1979), the preliminary outline of the final report was discussed and agreed upon. The following subjects were selected for intersessional work by separate Task Groups: (a) Interface Flux Modelling; (b) Toxic Substances; (c) Biogeochemical Cycles, and (d) A Review of Geographical Areas.

The approach proposed by the Group was approved by GESAMP at its eleventh session (Dubrovnik, 25 - 29 February 1979).

The final draft report prepared by the Working Group was reviewed and revised by the twelfth session of GESAMP (Geneva, 22 - 28 October 1981), and the revised version was endorsed by the GESAMP experts and all the eight co-sponsors of GESAMP for publication as GESAMP's response to the recommendation of the 1972 Stockholm Conference on the Human Environment.

CONTENTS

CONTENTS (continued)

EXECUTIVE SUMMARY

This presents the findings and conclusions of the Group, and in general is set out according to the terms of reference given in the preface.

1. Substances, activities, processes and effects

Man's activities contribute substantially to the fluxes of certain elements in the marine environment. For substances such as carbon dioxide, cadmium, arsenic, lead and mercury, fluxes of anthropogenic material approach or exceed the natural fluxes. Increased concentrations of lead, some radionuclides and carbon dioxide can be detected in the open ocean.

Many contaminants, particularly carbon dioxide and some metals, circulate widely in the atmosphere, and enter the oceans on a global scale primarily through the air-sea interface. Carbon dioxide is a significant environmental contaminant. Its principal direct impact is expected to be in the atmosphere and on the climate, and since this is being intensively investigated by several international expert bodies, carbon dioxide has not received detailed attention in this first report.

Trends in concentrations of some pollutants can be detected in the open ocean as illustrated by the presence of human-derived tritium at the Bahamas, of caesium-137 at the Arctic boundaries, and of increased levels of lead in open-ocean surface layers. Increased contamination in the form of tar-balls and oil-slicks, and, in some areas, elevated heavy metal levels are being seen along shipping routes, transportation by sea being a major use of the ocean. There is also the suggestion of decreased trends, for example in DDT and PCB concentrations, at higher latitudes of the northern hemisphere. On the other hand, there is the expectation, supported by some evidence, of increased concentrations of these compounds in the southern hemisphere and lower latitudes of the northern hemisphere.

The ocean surface microlayer controls the input of many gases and is a zone of high concentration of some substances, including heavy metals, organochlorines, and petroleum. No serious damage is known to have been done to this important interface by contaminants, although the potential exists for altering fluxes by the introduction of substances causing surface films. In this context, data from the Marine Pollution (Petroleum) Monitoring Pilot Project (MAPMOPP) of the Integrated Global Ocean Station System (IGOSS) indicate that of the area monitored, which included the major shipping lanes, between .05 and 0.1 per cent of the sea surface was covered by oil films at any given time.

Many substances eventually reach the sea floor. There they interact with the marine sediments and biota at the sediment-water interface. As yet, serious damage is known to have occurred only in very localized regions.

Some contaminants, such as radionuclides, halogenated hydrocarbons, and trace metals, can be detected at considerable distances from their sources, partly because of their world-wide transport by wind and ocean systems, and partly because sensitive methods are available for their detection. The controlled disposal of

low-level radioactive wastes in coastal and deep ocean waters is governed by the guidelines and protection limits for the general public recommended by the International Commission on Radiological Protection (ICRP). The dumping of packaged low-level wastes is governed by the London Dumping Convention and the guidelines and recommendations of the International Atomic Energy Agency (IAEA). Compliance with the spirit and intent of these regulations should ensure that the radiation exposure to human populations does not exceed internationally recognized standards.

There is no confirmed record of human illness having been caused by consumption of marine organisms due to their content of PCBs. However, the concentrations of PCB residues in some marine organisms exceed the level set by some national authorities in order to safeguard human health. On the ecological side, it is suspected that seals in some regions have suffered reproduction damage. The pathways and fate of DDT and other organochlorines are becoming reasonably well understood in the marine environment as are the toxic effects of their metabolites. DDT residues in seafood are not likely to place man at risk but fear of contamination from this and other sources could damage the marketability of seafood.

Pollution is generally most severe in semi-enclosed marginal seas and coastal waters bordering highly populated and industrialized zones. Such areas have substantial concentrations of contaminants from land-based sources. The environmental effects vary from one part of the coastal zone to another depending on the type and volume of the wastes, and the nature of coastal activities. Many pollutants introduced to the coastal zone remain there, at least temporarily.

Major chronic inshore marine pollution problems can often be attributed to the discharge of large volumes of wastes that have a local impact. These include materials which are partially biodegradable, such as raw sewage, sewage sludge, food and beverage processing wastes, pulp and paper mill effluents, woollen and cotton mill wastes, and sugar refinery effluents. Solid wastes such as mine tailings and dredge spoils are also in this category.

For sewage, problem areas are local rather than global, and coastal rather than oceanic. Sewage does present a direct risk of infections to humans on some beaches, especially during recreational seasons. Discharge on or near shellfish beds presents a greater risk to human health through the consumption of contaminated seafood.

Nutrient increase is often associated with sewage, and the impact of this has been perceptible in many coastal regions. The effects of nitrogenous wastes are usually most obvious, but phosphate may adversely alter the species composition of regional phytoplankton.

Heavy metal effects are difficult to detect in the field since they may be disguised by the effects of other wastes discharged simultaneously. The heavy metal concentrations in shellfish and fish which are generally recorded do not suggest any threat to the average human consumer, and they rarely damage the ecosystem - organisms seem able to adapt or withstand high environmental levels. Mercury, in the form of methylmercury, has caused damage in particular circumstances. Mercury is sometimes present at the top of the food-chain at concentrations considered toxic to man, but mercury levels in the open ocean are below those that are known to damage marine life. Selenium usually exists at levels which can have an antagonistic effect to those of mercury.

Effects of oil released into the marine environment depend on the type of oil, the nature of the ecosystem affected, and on a variety of physical, chemical and biological processes important to its fate that may be operative at the time of release. Oil spill effects on pelagic communities are rarely drastic and recovery

is usually a question of weeks or months. Impact on intertidal, and subtidal communities may be severe with recovery taking years or decades particularly in the shoreline communities where oil penetrates the sediments, and oil on beaches can seriously affect their amenity as recreational areas. Birds are particularly at risk, but there is no evidence that oil alone can threaten species survival.

The vast bulk of marine fishery resources (more than 90 per cent) is located in continental shelf areas and in the upwelling regions of the oceans. The coastal fisheries are particularly exposed to the effects of pollution, since the highest concentrations of metals, halogenated hydrocarbons, petroleum hydrocarbons, suspended solids and litter are found in these areas. Effects of pollution on fisheries tend as yet to be local or regional.

The transport of natural and anthropogenic substances through the ocean depends on a complex system of interacting physical, geochemical, and biological processes. The importance of atmospheric fluxes across the air-sea boundary and the oceanic flux of particles has only recently been recognized. Knowledge of fundamental processes is not extensive enough for the identification or quantification of the oceanic pathways for many substances. Other assessments of the effects of marine contaminants will depend upon increased knowledge of these processes, and especially those that can lead to a rapid and sporadic exchange from one region to another. Particular emphasis needs to be placed on transfer mechanisms from the coastal zone to the deep sea, such as can be caused by eddies or sediment slumping.

Regional co-ordination of pollution studies is vital for effective development of programmes and for assurance of good quality data that can be compared from one area to another. Co-ordination in the North Atlantic is effected by the International Council for the Exploration of the Sea (ICES) and in several other regions by the UNEP Regional Seas Programme. The programmes of these bodies can be regarded as models for such efforts. There are now a number of international conventions, at the regional or global levels, designed to protect the marine environment, and the agreements formulated in these treaties provide an essential legal framework within which international collaborative programmes can be encouraged to operate.

2.   Evaluation of the present state of the health of the oceans

We may now attempt to assess the health of the oceans at the present time, some ten years after the Stockholm Conference on the Human Environment.

The progressive development of complex industrial technology produces large amounts of waste which must be disposed of without causing intolerable effects. Even after recycling and treatment there are waste residues. This generates a continuing pressure on the marine environment and we must ask to what extent evidence of that pressure can be recognized in the sea.

In the open sea we have not detected significant effects on the ecosystem. Trends have indeed been observed of the concentrations of several contaminants, some up, some down, but these are not reflected in environmental deterioration.

On the other hand, effects can be seen in semi-enclosed seas, shelf seas and coastal zones. Semi-enclosed seas, like the Gulf of Mexico, the Mediterranean Sea, the North Sea and the Baltic Sea receive substantial contamination. In some cases the living resources have been locally contaminated to such a degree that fisheries have been stopped in limited areas, sometimes leading to suspicion among consumers that fish caught elsewhere in adjacent areas may be contaminated and thus causing

problems for the marketing of fish from whole regions. In a number of local "hot spots", the ecosystem balance has been disturbed, e.g., due to eutrophication. In one area of the North Sea (the Waddensea), and in the Baltic Sea, pollution has been implicated in reducing the populations of some marine mammals.

The use of the coastal zone for sewage disposal is world-wide and the input is increasing. Incidents have occurred when human health has been severely threatened as a result of the sewage load in the coastal zone, and in places the nature of the habitat has been altered and the species composition of plant and animal populations changed. There are also records of the ecosystem recovering and returning to normal when proper control has been instituted. A proper management of sewage disposal and a re-examination of sewage disposal practice are necessary, otherwise the combined effects of many local disturbances could become serious on a regional and perhaps gradually on a global scale.

The importance of living marine resources as a protein source is increasing. Fisheries management has in recent years prevented complete destruction of several threatened fish stocks, and it is clear that the practice of management must continue and develop. Adequate management requires an assessment of all pressures on the stocks - pollution as well as fishing.

Mariculture is expanding in many coastal zones, and without proper management its effluents could pose a local threat to environmental conditions, although mariculture is itself very dependent on good water quality, and cannot be developed unless this is properly protected.

It is not only the living resources which are concentrated at the continental margins of the oceans, but also the currently utilized non-living resources. Several incidents have occurred during the last decade when large amounts of oil have contaminated the sea from spills and blow-outs. However, no long-term damage to open-sea ecosystems has been detected. Mineral resources are being worked in the coastal zone and effort will increasingly move into the deep sea in the future. At present the effects are localized. Various types of construction (harbours, hotels, etc.) present another growing pressure on the coastal zone. The hazard due to shipping is also concentrated here and it is along the shores that man finds most use of the sea for recreation.

The impact of the many activities which affect the coastal zone is increasing, and detrimental effects can already be detected in the local disruption of habitats. Some types of ecosystem, such as coral reefs and mangroves, may be particularly at risk. Proper management has often succeeded in preserving or restoring the environment and there is reason for concern where such management is lacking. Adverse effects on the coastal zone and shelf seas could gradually spread, both along the shelf sea-area and towards the open ocean. We therefore strongly urge continued and increased effort to protect the coastal zones and semi-enclosed seas by appropriate management and control, supported by research and international agreements. The marine environment of the coastal zone is vital to mankind, on a global as well as on a local basis.

3. Problems requiring further examination

The pollution problems discussed in this report arise directly or indirectly from the rapid increase in industrial and agricultural activity so that a related increase in emissions and effluents is expected. In particular, a larger volume of sewage may need to be disposed of, industrialization will spread, and further energy production will be required, even if economic factors slow down development for a time.

It is important that the spreading of pollution from the coastal zone to the deep sea and the dispersal of contaminants from deep-sea dump sites be further studied. One important aim should be to identify and quantify the exchange fluxes and pathways. In this connection a balanced approach to the development and use of models and research into the critical fundamental processes should be encouraged.

The environmental conditions in the less developed regions of the world such as the Arctic and the oceans of the southern hemisphere need to be further studied. It is important in these areas to assess the sensitivity of the physical, chemical and biological processes prevailing, as well as to determine the transport, behaviour and potential impact of pollutants. Certain ecosystems like mangrove swamps and coral reefs need special attention.

Concerning energy, the extension of oil exploration into extremely hostile ocean areas may give rise to major spills and greater low-level inputs. Production is expected to increase in cold areas where oil degrades more slowly. Nuclear power is being developed in several countries which see this as essential to their energy requirements so that increased discharges of low-level radioactivity and further marine dumping of wastes can be expected. If any of the several attempts to win energy from the sea by unconventional methods are successful, effects of this must also be considered, and proper control instituted.

If deep-sea mining becomes economic and if an active industry develops, potential effects should be assessed, and again any necessary control instituted.

Even in the present economic climate, tourism seems to be increasing, as predicted by the Organization for Economic Co-operation and Development (OECD), and this will step up the pressure on the shallow sea regions, not only by sewage input but also by habitat destruction in the coastal zone.

New techniques for waste disposal should be evaluated. Thus the incineration of chemical wastes at sea, and the burial of contaminated solid waste in the sea bed under a cap of clean sediment should be kept under review.

The most damaging effects on the ecosystem have been recorded at "hot spots". These may range in size from a few square metres round a discharge pipe to the full extent of a major estuary, and they may encompass specific habitats or ecosystems such as salt marshes, kelp beds, mangrove swamps and coral reefs. Most of these future threats, like the present problems discussed in this report, will have their main potential impact on the coastal zone. Thus the extent of the interchange between the most impacted nearshore zones, the remainder of the continental shelf, and the open ocean is highly relevant. Although published work suggests that nearshore ecosystems export significant quantities of material, this view is now being re-examined, and further work on the topic is of major importance in assessing the spread of pollution. Initially this may be regarded as a restricted or local problem. However, if a high proportion of a given habitat becomes affected, then the pollution could become global in the context of that habitat.

Man is becoming a dominant part of the ecosystem in many marine regions, due to his various uses of the marine environment, and the health of the marine ecosystem is an important factor in man's own existence. Man's importance has long been recognized in terrestrial ecosystems. Studies to understand the future development and changes should be interdisciplinary and include ecologists.

New chemicals are continuously introduced in the commercial, industrial and medical fields, and many of these will inevitably find their way into the sea. Chemicals in present use but not previously found in the marine environment cannot

be ruled out as potential contaminants of the sea. Among organic chemicals, a list of some thirty compounds or groups of compounds has been noted, and in particular phthalates, toxaphene and low molecular weight hydrocarbons can be emphasized as requiring examination.

The important issue is perhaps not so much to name new potential pollutants but rather to develop a strategy for approaching the problem. Continuing development and standardization of analytical techniques is one important part of the problem.

Over the past two decades methods have been employed to regulate the introduction of radioactive materials to the sea. These are based on the concept that there exists an environmental capacity which can be calculated using critical pathway techniques. The utility of the application of this approach to the controlled release of other materials is worthy of careful consideration.

It would clearly be difficult if not impossible to search the seas for all potential contaminants and to monitor their concentrations. A more reasonable approach is to focus on those known toxic substances that are produced and used in large quantities, or to concentrate the field effort on geographical areas of known input, and to obtain the data necessary to achieve better predictions of environmental impact. In this context, there exists a strong case for monitoring selected substances in the ocean.

There are several inputs of pollutants, or potential pollutants, and some activities which are characterized by increasing trends. Some of the reasons for concern are as follows:

Input or activity	Concern
1. CO_2	Climate shift, temperature change, sea-level change etc.
2. Metals	Potential toxic effects
3. Micro-organisms	Public health risk
4. Radioactive waste disposal	Public health risk
5. New chemicals	Toxic effects on man and organisms
6. New energy production	Alteration or disturbance of habitats
7. Deep-sea mining	Increased turbidity, sea-bed disturbance

It should also be stated that a general increase in contamination from various sources will pose a threat to specific habitats.

4. Concluding remark

The Group noted that although effects of pollution have not so far been detected on a global scale, general trends of increasing contamination can be recognized in some areas, and these trends are warning signals. The signals are noticeable mainly in the marine areas most intensively used by man, viz. coastal

waters. The oceans are capable of absorbing limited and controlled quantities of wastes and, as such, represent an important resource. But careful control of waste disposal is necessary. Programmes must be maintained for this purpose and initiative taken to regulate the entry of new contaminants to the oceans. The effects of pollution should be carefully monitored, and our understanding of the fate and effects of pollutants in the oceans must be improved. This approach makes for more accurate predictions and assessments and therefore provides the most effective means of ensuring that the health of the oceans is maintained.

CHAPTER I

SCOPE AND PURPOSE OF THE REPORT

This report assesses the condition of the marine environment ten years after the United Nations Conference on the Human Environment (Stockholm, 1972). Since then the human uses of the environment have been continuously increasing and new technologies have been developing. Marine pollution has been defined by GESAMP as:

"Introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairing of quality for use of sea-water and reduction of amenities."

This definition implies that marine pollution is caused by the introduction into the marine environment of substances and energy which have adverse effects, that marine pollution may be related to its sources and that polluting substances are dispersed through the marine environment by various processes.

The aim of the report is to evaluate the conditions and quality of the marine environment in relation to man's various uses of the ocean; i.e., to assess the health of the ocean. One requirement for making an accurate assessment is a reasonably good understanding of how the oceanic system works. The lack of reliable, intercomparable data on pollution levels in the marine environment at present makes such assessments uncertain except in a few situations. Ideally, effects in the environment should be related to levels of inputs which require a knowledge of dose-response functions. This knowledge is only gradually emerging.

In assessing pollution of the sea, it is useful to consider the analogy of human health. This cannot easily be defined in an exact or quantitative way. It comprises consideration of morphology, physiology and behaviour, and although there is no clear "normal" to which every individual should conform, it is possible to recognize good health as a condition of general well-being and bad health as a malfunctioning of the body. In detecting the symptoms of ill health and relating them to the underlying causes, an understanding of the structure and function of the body is required; anatomy and physiology must be looked at before pathology. By analogy, the detection and evaluation of adverse changes in the marine environment require an overall concept of the various components of the ocean and how they act and interact. The open sea, the main body of the system, must be kept in good health, but the extremities - the estuaries, lagoons and shallow waters, cannot be neglected, and deterioration there, if allowed to progress, might affect the whole body. The marine environment is a system where physical, chemical and biological processes interact and which, when operating satisfactorily, maintains a balanced range of diverse plants and animals and is available to man for a variety of uses. This is the sense in which we define the health of the oceans and this philosophy accounts for the the approach and the structure of the report.

Thus, the marine environment is taken to include estuaries, coastal waters and the open ocean. It is recognized as an area where man extracts living and

non-living resources, which is used for recreation and waste disposal and which plays a fundamental role in maintaining present conditions for life on the earth. The report also pays attention to possible detrimental effects of pollution on the global marine ecosystem as it relates to climate and atmospheric conditions essential to man's survival. Global aspects are emphasized, although the importance of local problems is accepted and several geographical areas have been examined and used for model studies and assessments.

The ocean cannot be regarded as an isolated entity since it interacts intimately with the atmosphere, the sea floor and the continents, from all of which it receives inputs. In view of this, the consideration of processes that affect the fluxes both within the marine environment and between the ocean, continent and atmosphere has been given a major place in the report. This constitutes what has been called here the interface-flux model approach. The basic philosophy has been that it is necessary, as stated earlier, to take into account the interaction of physical, chemical, biological and geological processes in order to understand changes in the marine conditions, their causes and effects.

A flux model approach, consisting of two parts, namely the formulation of an interface-flux model followed by the modelling of biogeochemical fluxes of selected substances, must be supplemented by consideration of individual substances and geographical regions. Accordingly, the production, input, distribution and characteristics of individual pollutants have been considered. Rather than treating a long list of substances, five categories have been selected for this first report: sewage, organochlorines, petroleum, metals and radionuclides. In this first report on the health of the oceans, a limited series of problems has been considered, others having been left for subsequent reports. The carbon dioxide problem, whilst recognized to be significant, has not been dealt with here since it is currently being examined by other specialized bodies such as the Special Committee on Problems of the Environment (SCOPE) and within the World Climate Research Programme (WCRP) of the World Meteorological Organization (WMO).

Considering that most marine environmental studies have been done in coastal zones, it was also decided to assess the situation in various geographical regions. Many pollution problems, e.g. eutrophication, have been localized to restricted areas of the coastal zone. Although generalizations can be made as to the function of the natural system, pollution problems should be considered on a case-by-case basis. It is unwise to extrapolate results from one area of the globe to another. It should also be recognized that man's use of the resources of the ocean can have a profound influence on the natural systems, as shown by the effects of over-exploitation of commercial fisheries.

The report is addressed to scientific administrators and decision-makers concerned with the state of the marine environment and its protection. It is accompanied by a Technical Supplement (IOC, in prep.) to be published by the United Nations Educational, Scientific and Cultural Organization (UNESCO). This volume is composed of papers which have been written by individual scientists, and which were used by the Task Groups mentioned in the preface. It provides background material and working papers, including references to the open literature, that were considered by the Group when making the statements and judgements presented in the report. The following chapters are factual and technical, and the main conclusions have been drawn together in the executive summary which precedes this chapter.

CHAPTER II

BASIC PROPERTIES OF THE OCEAN SYSTEM

II.1 Introduction

The Group recognized the need to consider fundamental processes in their examination of the health of the oceans. In this chapter the behaviour of the ocean system is discussed to provide a scientific basis for the later consideration of particular problems. Much of what is presented is given in greater detail in the Technical Supplement (IOC, in prep.).

The ocean environment is a complex system controlled by a variety of physical, chemical and biological processes. The understanding of these processes is a prerequisite of any consideration of man's past or future impact on the sea. For example, a substance introduced into the ocean at some location will be transported to other areas where it may cause effects harmful to man or the environment. Interpretation of limited data on the substance's initial spread, or prediction of its long-term transport, is only possible if the processes causing its transport are reasonably well understood. In this context it is often important to determine the most significant processes so that simplified models for the substance's transport may be developed.

The need to understand how the total system operates when assessing fluctuations in environmental resources has been exemplified by studies of changes in fish yield in the North Sea (Cushing - in press) and of deteriorating environmental conditions in the Baltic (Melvasalo et al. 1981) and the Mediterranean. The same, of course, holds true for marine ecosystems in general (Steele 1974).

Of particular interest in this context is the description of the processes, and their spatial and temporal scales, which are important in different oceanic areas and for different pollution situations. Along the coast, where man's impact is greatest, the shoreline is varied, riverine inputs influence many aspects of the environment, physical processes are relatively fast, and, in general, biological activity is high. Some of the material introduced into the coastal zone is transported to the deep sea where it is added to that which has crossed the air/sea interface, another important boundary of the ocean system. Here interior ocean processes control the large-scale flux of gases to the ocean as well as the rate of introduction of atmospherically-borne substances such as trace metals and organochlorines. Within the ocean, material is swept by the large-scale current fields to other regions while being mixed into adjacent water masses. Much will reach the ocean floor, sometimes relatively quickly by adhering to sinking particulate matter. At the sediment-water interface strong gradients lead to intense exchanges of substances with the sediments, some of these involving the living benthic community.

Thus, in the ocean interior and at its boundaries with the land masses, the atmosphere and the deep sediment, material introduced into the marine environment is subjected to various physical, chemical and biological processes that determine its

ultimate fate. The following sections describe in more detail what is known about each of these oceanic compartments. Figure II.1 provides a schematic representation of many of the more important oceanic regions and processes.

II.2 The coastal zone and continental shelves

At the boundary between the ocean and the land masses of the world, physical and biogeochemical processes occur that determine the nature of the transition from land and fresh water to a marine environment. They lead to the conditions that make the continental shelves, with their embayments, estuaries and lagoons, so useful to man. Here many of the world's important fisheries exist; ports and harbours serve as transportation centres, and much of the human population living close to the sea use the coastal zone for industrial activities, recreation and as a disposal area for municipal and industrial wastes.

From rivers the ocean receives some $4 \times 10^{16} dm^3$ per year of fresh water, an estimated $2 \times 10^{13} kg$ per year of suspended matter and dissolved salts including less well determined amounts of metal and organic contaminants both dissolved in the water and adhering to the suspended material. In the embayments and estuaries or on the open continental shelves, these interact with water and substances of oceanic origin. Some portion of the suspended and dissolved material, often in modified form, eventually reaches the open ocean.

The fresh water has a major impact on the nearshore environment. Where the input is strong enough, estuarine systems are formed that usually result in the inflow of saline oceanic water at the bottom and an outflow of less saline water at the surface. The intensity and nature of this estuarine circulation depends on many factors including the extent of mixing, usually by tidal currents, and the dimensions of the estuary.

The freshwater run-off also often produces seasonal variation in the nearshore stratification in both the estuaries and on the continental shelves. The mass of relatively light fresh surface water emanating from large estuaries on to the open shelf can also lead to complicated circulation patterns with vertical current gradients near the mouths. Away from the source region, the fresh water is entrained by the local shelf circulation but its buoyancy often causes variations in sea surface elevation at the coast and compensating offshore variations in the density field. The typical resulting alongshore transport of fresh water and other land-derived material from the estuary is then concentrated near the surface by the stratification.

The average and slowly-changing circulations on the shelf are usually forced by the surface wind which, because of the Coriolis effect, drives a surface transport water to the right of the wind in the northern hemisphere and to its left in the southern hemisphere. Alongshore winds thus transport surface waters on or offshore and force a compensating transport in the opposite direction at depth. In the case of persistent alongshore winds, an associated alongshore current, which can be stronger and more persistent than the flows across the shelf, is also driven in the direction of the wind. The large-scale open ocean circulation can also have important, indirect effects on mean coastal transports. On some continental shelves the sea surface slopes associated with the major offshore oceanic gyres can be transmitted across the continental shelf, resulting in a longshore transport that may be opposite in direction and stronger than the transport driven by the local mean wind.

Transient currents, including the tides, on the continental shelf are usually stronger than the mean and may result in the mixing and transport of water and

Figure II.1 : Schematic representation of major ocean processes

dissolved or suspended material in the horizontal and vertical directions. The non-linear interaction of tidal currents, for example, often leads to residual circulations in embayments, in regions of marked coastline curvature, and around submarine banks. Tidal flows also contribute to vertical mixing of the water column in shallow areas and can cause the destruction of the usual summer thermocline in regions where the mixing is strong enough to overcome the stratification caused by surface heating or freshwater input. At the edge of the shelf, internal tides create strong current gradients and localized vertical mixing, often leading to the exchange of material and water with the open ocean.

At the edge of the continental shelf the coastal wind systems can cause large-scale upwelling. Impinging offshore currents and eddies also promote large-scale exchanges between the coastal and offshore water masses. These processes can lead to significant shoreward fluxes of salt, heat and nutrients, as well as offshore fluxes of contaminants. In some places, canyons cut through the outer banks of the shelf and serve as sites of strong mixing and axial flows that transport shelf water and sediment across the shelf.

The coastal waters can sometimes be considered as somewhat isolated from the open ocean and as having relatively distinct properties over large areas. This has led to considerations of a flushing or residence time for a coastal zone which can be defined as the approximate time required for the replacement of the total volume of coastal waters with water from offshore or from other distinct regions of the shelf. Estimates of typical flushing time for continental shelf regions vary from a few months to a few years. Any extension of this simple concept to substances introduced into the coastal regions must take account of all the biogeochemical processes to which the substance is subjected. Even then the concept of a residence time must be treated with caution.

Of the particulate material that enters the embayments and estuaries along with the fresh water, it has been estimated that only ten per cent reaches the deep ocean. The remainder accumulates in the coastal sediments. The behaviour of individual elements dissolved in the incoming water depends on a complex interplay of a number of chemical, physical and biological processes which vary with the estuary and geographical region. A substance may undergo various simultaneous or consecutive changes. An ionic or molecular species may undergo oxidation or reduction, or be adsorbed on particles. The particles may grow by interpenetration and/or be aggregated by adhesion (flocculation) resulting in accelerated sedimentation, especially in stratified estuaries. There can be desorption of adsorbed species either as a result of reduced surface availability or through a change in adsorption equilibria. A change in solubility of some surface-active material occurs with changes in salinity.

The situation is further complicated by variation in the controlling parameters through the estuarine zone and the continental shelf. Salinity influences the rates of flocculation, as well as many of the chemical properties. The suspended particulate load varies not only with the removal of introduced material but also with the intensity of resuspension by physical processes. The redox potential or oxygen concentration varies horizontally and vertically in many estuaries so that elements or substances that exist in two or more oxidation states depending on the redox potential, may do so in different parts of the same system (Jenne 1979). Some elements may be rapidly adsorbed on suspended particulate matter and released more slowly in a different form. The pathways of many materials, such as trace metals, are only beginning to be understood as analytical techniques have recently reached the state that allows measurements made at various times and places to be compared.

The primary sedimentation zone probably never reaches equilibrium and its

chemical and physical transport properties involve different time scales that are still to be determined. Consequently, it is difficult to make predictions about the total amount of a contaminant that will reach, or has been reaching, the open ocean (Burton and Liss 1977).

Humans can modify the concentration and fluxes of chemical elements to the ocean. This often occurs through increases in the discharge of solids and dissolved material by rivers. For example, as a result of pollution a relatively small river such as the Rhine at present exports ten times more chloride than at the beginning of this century and now equals that of the Amazon river (UNESCO 1981).

Deforestation and overgrazing have generally increased the riverine solid discharge although in some instances river outflows have been reduced by damming or by withdrawal of water for irrigation. This can also affect the dissolved load through carbonate precipitation and salt retention in soils. The examples of the Indus and Nile are well known for their detrimental effects on coastal zone erosion and a drastic decrease in the productivity of fisheries.

Human influence may severely affect speciation of chemical elements and biogeochemical processes. The increasing amount of nutrients and organic matter discharged into riverine and estuarine waters can enhance nearshore productivity. In extreme cases the subsequent degradation of organic matter results in an anoxic environment and enhanced dissolution of some elements, such as manganese. Some organic contaminants such as detergents can modify the electrical charge of particulates and subsequent ionic exchanges as well as the rate of ecological metabolism. The discharge of chlorinated waters into the coastal zone can generate new chlorinated and brominated organic substances, the possible consequences of which in marine waters are only now being understood (Block and Helz 1977). Man's influence at the land-sea interface is discussed in more detail in later chapters.

II.3 The ocean surface

At the surface of the ocean a thin layer, in general less than 1 mm thick, and a micro-environment in itself, plays a dominant role in controlling the rates of exchange of solids, liquids and gases, including contaminants, between the atmosphere and the ocean. It also supports a unique community of organisms. Being the intersection between the air and the sea, its physico-chemical properties and limited volume make it the site of important concentrations of materials, especially trace elements and organic molecules, including petroleum constituents and organochlorines.

It is now recognized that for some substances the atmospheric input is quantitatively similar to or greater than river inputs. For example, it is known that the influx to the open ocean of zinc, cadmium, lead, mercury and selenium by aerosols is more than 50 per cent of the total terrestrial influx. A significant fraction of substances synthesized by man are also transported to the ocean via the atmosphere. These include fluorochlorocarbons, high molecular-weight chlorinated hydrocarbons, and the radionuclides of plutonium and americium. Most substances, both organic and inorganic, move in both directions between the ocean and atmosphere but there is a resultant net flux into the ocean. Knowledge of the fluxes of anthropogenic sulphur, carbon dioxide, and some of the low molecular-weight chlorinated hydrocarbons is complicated by relatively large natural sources of these materials (GESAMP 1980c).

In both the ocean and the atmosphere, gases are transported across turbulent boundary layers to a thin near-surface region where molecular processes are dominant. The rate of transport of gases across this inner molecular layer is

controlled either by their diffusion in the gaseous phase (e.g. H_2O, SO_2, NO_2, NH_3) or in the aqueous phase (e.g. CO_2, O_2, CH_4, N_2O). For gases whose exchange is controlled by the gaseous phase, it is possible to calculate exchange rates using knowledge of the concentration difference between the ocean and atmosphere, the strength of the surface winds, and certain empirical relationships which take into account important processes in the turbulent boundary layers. For those gases controlled by their diffusion in the aqueous phase the situation is more complex and their possible reaction with the water must be taken into account. Certain phenomena of gas exchange remain unexplained. Quantitative calculations of exchange fluxes are usually unreliable except perhaps on a global scale where the process of averaging may tend to eliminate the effects of some of the unknown factors.

Heavy metals, sulphates, radionuclides, organics, and micro-organisms are transferred from the atmosphere to the ocean in dry fall-out and precipitation. In the oceanic surface mixed layer these substances can be transported back to the surface by air bubbles, which scavenge interfacially-active material during their rise through the water and eject some of the adsorbed material into the atmosphere when they burst at the sea surface. The enrichment of contaminants on the bubble surface and in the surface microlayer can lead to the enrichment of the adsorbed contaminants in the atmosphere relative to their concentrations in sea-water. Bubbles also increase the surface area available for gas exchange but most evidence indicates that gas exchange via bubbles is not as important as other mechanisms discussed above.

The physico-chemical properties of the sea-surface have a fundamental effect on the processes that move chemicals across the air-sea interface. Organic chemical reactions determine the selective complexation of metal ions, and their accumulation at the ocean surface. Exchange reactions occur between amino acid-metal complexes and fatty acids, or their calcium and magnesium soaps. These are not well understood in sea-water but may be the key to speciation in the interfacial transport of metal ions. Simple models of trace-metal binding by organic material in the water near the sea surface have been developed to predict the enrichment of metals in a microlayer and in aerosols. The agreement between the predicted enrichment and that measured in the field is generally satisfactory, except for iron and lead in the microlayer and mercury and cadmium in aerosol samples. Other processes are expected to be important for these metals.

Marine plants and animals may be involved in air-sea interchange in a number of significant ways. They produce surface-active organic material which can alter exchange through the formation of films at the air-sea interface and on air bubbles and particles moving towards the interface. The organic phases and films may accumulate oleophilic contaminants, such as hydrocarbons, chlorinated hydrocarbons, and organic compounds of heavy metals. Through the utilization of carbon dioxide and release of oxygen by marine plants as a result of photosynthesis, and through the comparable processes related to respiration by bacteria and marine animals, marine organisms play a principal role in maintaining a balance of these gases.

The surface microlayer is enriched in pollutants compared to waters directly beneath it; relatively little information exists on levels of pollutants in the organisms inhabiting this zone - the pleuston that live on the surface and the neuston that live immediately beneath it. Of importance is the potential of these organisms to transport contaminants out of this highly enriched layer through predation and by the excretion of particulates.

It has been demonstrated that bacteria can be enriched in the surface microlayer by bubbles, and projected into the atmosphere by bubble bursting and from surf spray. There is now evidence that some pathogenic micro-organisms are transmitted through the atmosphere, but it is uncertain how epidemiologically

significant the transfer of these micro-organisms from the sea to the land through the atmosphere might be.

There are three known types of organic contaminants that could modify the chemical and physical properties of the air-sea interface: detergents, the complex mixture of organics in municipal wastes and sewage sludge, and petroleum hydrocarbons. Of these, some detergents are short-lived in the sea surface because of their high solubility and relatively high bio-degradability, and there is no documentation of cases in the open ocean where detergents have significantly influenced sea-surface properties. Surface tension reduction due to organic contaminants has been associated with marine dump sites for municipal wastes. The potential for accumulation of oleophilic pollutants in the surface films associated with such dump sites and of their possible transport into the marine atmosphere have been identified (NRC 1974).

Petroleum hydrocarbons and their derivatives influence the physics and chemistry of the air-sea interface in numerous ways. Petroleum films not only affect material transport and physical parameters, but also influence the absorption, transmission, and reflection of electromagnetic radiation. Petroleum in and on the sea may affect the pathways of contaminants by dissolving other oleophilic substances such as halogenated hydrocarbons and by reducing the interfacial contaminant transfer rate. Exchange rates are decreased by oil films, through attenuation of waves and by the alteration of breaking waves, spray and the number and size distribution of bursting bubbles, although the significance of such effects on an oceanic scale remains to be demonstrated.

The assessment of the regional and global impact on interfacial processes requires knowledge of the extent of sea-surface coverage by petroleum films, which, because of the great influence of wind and waves, is likely to be a function of average wind conditions. In the summer a broad band from the equator to a latitude approximately 40 degrees south is relatively calm and has the potential for persistent sea-slick formation. In the northern hemisphere low winds exist during the summer in some regions of the northern seas, the Black Sea, the Mediterranean Sea, and in a few zones along the Tropic of Capricorn. Although recent analyses indicate that, at the present time, petroleum films do not modify the global exchange of matter or energy significantly, in certain coastal areas and seas, especially along shipping routes, such films may be more prevalent and could have local effects (GESAMP 1980c).

Calculation of the air-sea exchange fluxes for heavy metals is complicated by their natural introduction into the atmosphere from crustal weathering, the terrestrial biosphere, volcanoes and the sea. Many heavy metals have marine atmospheric concentrations exceeding those that can be expected from consideration of crustal weathering or bulk sea-water composition (NAS 1978). These relatively high concentrations may be related either to human actitivies or natural geochemical processes that are not yet understood. Very significant quantities of these metals are being transported in both directions across the air-sea interface, making it very difficult to evaluate their net total flux to the ocean from the atmosphere. The net flux of material from the land to the ocean also remains to be properly evaluated.

All the substances that cross the air-sea interface are subject to mixing throughout the upper-ocean mixed layer and subsequent downward transport either in soluble form or adhering to particulate matter. The rate at which this transport takes place, removing potential pollutants from the upper ocean, depends not only on the dynamics of the mixed layer itself but also on the processes taking place in the underlying oceanic water column (section II.4). Some substances eventually re-enter

the surface layer through similar processes as well as by rising bubbles and upward biological transport.

II.4 The open ocean

Physical, chemical and biological processes in the open ocean determine the rates of transfer of energy, momentum and substances to and from the land, the air and the sedimentary boundaries and control their distribution throughout the ocean basins. Because of the difficulty of measuring these processes directly, much of what we know about them is inferred from studies of oceanic properties and their distributions.

The ocean is characterized by large-scale temperature and salinity gradients which arise from the differences in the fluxes of heat and water across the surface in the polar and equatorial regions. At the poles, the heat loss leads to the formation of cold dense water masses that sink into the deep sea and spread throughout the ocean basins, determining the temperature and salinity characteristics of the deep waters and causing strong vertical gradients in these properties at equatorial and mid-latitudes. Associated with this thermohaline circulation are various deep boundary currents and a gradual return of the deep waters towards the surface at an ocean-wide average rate of only a few metres a year.

The ocean is also driven by large-scale atmospheric wind-systems. These lead to extensive gyres in all the ocean basins between the equator and mid-latitudes and the strong western boundary currents, of which the best known examples are the Gulf Stream in the Atlantic and the Kuroshio in the Pacific. These strong current systems shed warm- and cold-core eddies that can transfer heat and materials and may impinge on the continental shelves causing exchanges with the coastal zone. Other features of the oceanic circulation such as coastal upwelling along the continental shelves (e.g. on a large scale off Peru), the Antarctic Circumpolar Current, and the east-west current systems near the equator are also primarily wind-driven.

Fluctuating motions on various temporal and spatial scales exist throughout the ocean basins and almost everywhere have amplitudes greater than the mean. Dominant among these fluctuations are the meso-scale "eddies" that typically have horizontal scales of the order of a hundred kilometres and various vertical expressions. Most are thought to arise from the instability of the large-scale current and density fields, although some are forced directly by the atmosphere. Meso-scale eddies provide the strongest horizontal mixing or stirring, often giving transfer rates exceeding those from transport by the average ocean currents. Although they exist throughout the ocean basins, the eddies vary greatly in intensity over several horizontal scales, and thus result in a non-uniform transport mechanism.

There are also smaller-scale spatial and temporal features throughout the ocean. Examples include the tides, inertial and internal waves, and thin layers in the temperature or salinity fields. All but the smallest of these are constrained by the oceanic stratification so that they have much greater horizontal than vertical scales and currents which lie more or less along the density surfaces. They do, however, lead to mixing across density surfaces, especially around the ocean's edges. The magnitude and nature of this vertical mixing remains obscure, although it is known to lead, on the average, to vertical exchanges no greater than those arising from the slow upwelling of deep waters.

Of importance to the transfer of oceanic properties is the fact that the physical transfer by the mean currents and various mixing mechanisms in the open

ocean is primarily along density surfaces, which lie almost horizontally. Where the density surfaces intersect the mixed layer at the ocean's surface or at its floor and sides, exchanges between the mixed layers and the ocean's interior may occur, but substances once introduced into the interior are strongly constrained to stay on the density surfaces. This may be seen in the oceanic distribution of various water masses which may be traced in some cases from a single source along density surfaces throughout the world's oceans. Only in the northern and southern oceans, where water mass formation takes place through deep overturning processes, is transport across density surfaces substantial. Tritium was introduced into the surface ocean as a result of nuclear weapon testing in the 1960s and was sampled by the Geochemical Ocean Section Study (GEOSECS) expedition during 1972-73. The western Atlantic distribution (figure II.2) clearly shows the properties discussed above; namely, inflow at mid-latitudes along density surfaces which intersect the ocean surface, and deep penetration in northern latitudes where the surface input was also particularly strong.

Although much is known of the physical properties of the ocean, some basic balances are poorly understood. One may note that the ocean's role in transferring such a fundamental quantity as heat between the equator and the poles, a matter of great importance to the world climate problem, is the subject of intensive scientific research but remains unquantified. Our ability to predict the transfer of a contaminant subject to the same processes is therefore also limited.

The interaction of physical, chemical and biological processes in the open ocean is exceedingly complex. It is increasingly recognized that the gross features of the depth distribution of nutrients (phosphate, nitrate, silicate) and trace metals (e.g. copper, cadmium, zinc and nickel) arise from a combination of the transport by physical processes and the transport by oceanic particles.

Most suspended oceanic particles are in the size range of 1-100 um. The smallest settle at rates of only several hundred metres a year, whereas the largest can reach the ocean floor in a few days. The finer particles are composed primarily of biological skeletal and inorganic detrital material. Larger particles which account for the vertical mass-flux are mainly faecal pellets and other biogenic material. Their abundance depends on the introduction of inorganic material at the sea surface and edges and, more importantly, on the level of biological activity at their source. On their descent to the ocean floor, particles add to or remove dissolved elements from the water column. This effect was clearly to be seen in the rapid introduction to the marine sediments of the radioactive isotopes of strontium, caesium and plutonium from atmospheric nuclear testing.

Quantification of the role of particles is difficult. Direct use of the observed distribution of nutrients or trace metals such as cadmium, zinc, nickel and copper, or of the strong correlations between them or with oceanic nutrients, would require greater knowledge of physical processes than is available. Direct measurements of particle concentrations and fluxes are difficult, but are becoming available. In addition, the chemical processes involved in the water-particle interactions are very complex. Particles as small as clays are involved in biological cycles. Chemically-active elements undergo complex mineralization - solubilization processes. Those elements involved biologically, recycle between the particulate and soluble phases within the water column down to different depths, depending on their chemical and biological behaviour. Because of the geographical variation in biological activity, the vertical transport of elements by particles should produce horizontal gradients in the water column. The situation is complicated, however, by the strong horizontal physical transfer mechanisms which will tend to smooth out the horizontal differences. Some elements, such as phosphorus and cadmium, are released as their organic carriers are destroyed during sinking. Regeneration of various elements also takes place at different depths:
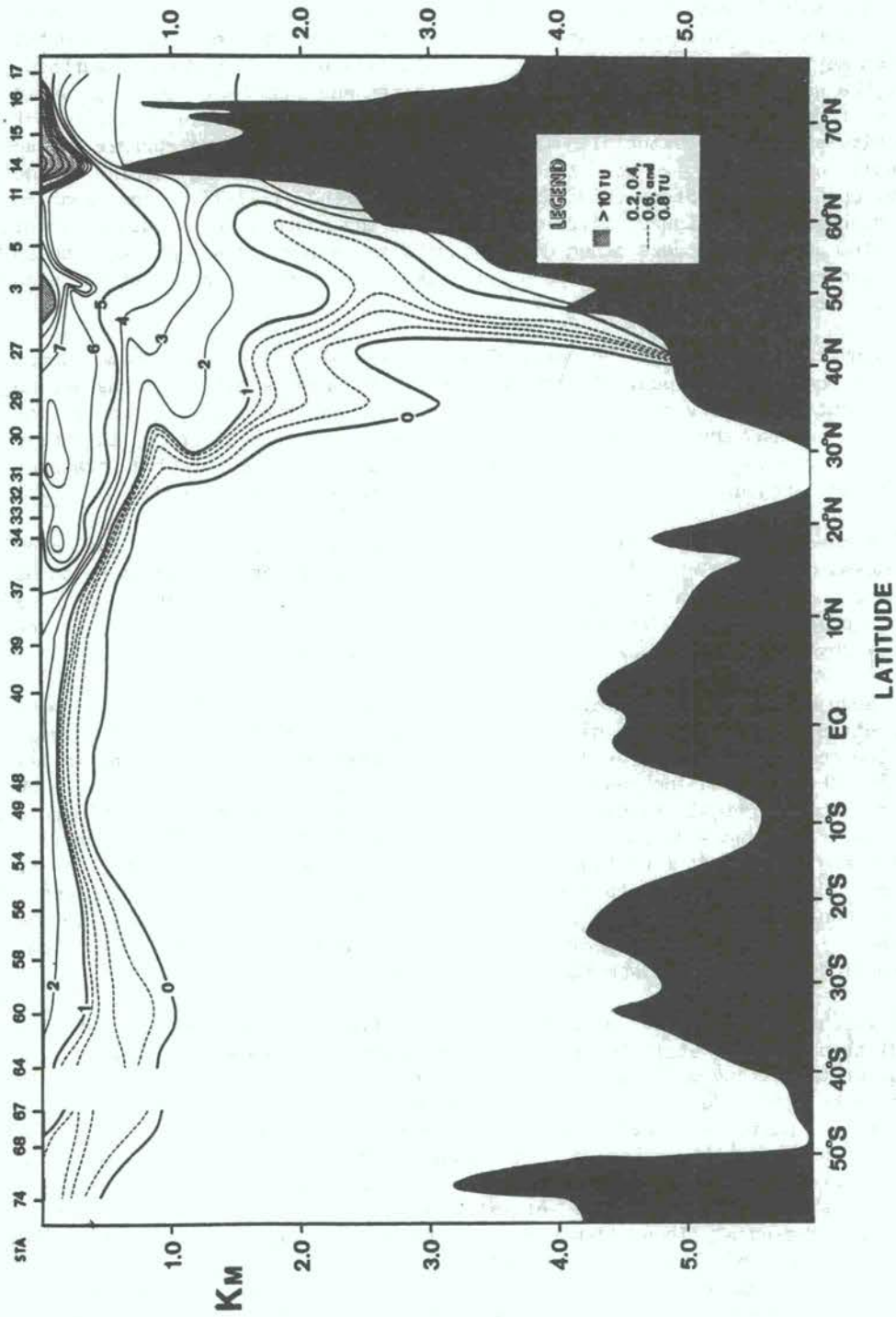
Figure II.2 : Western Atlantic tritium during GEOSECS taken from Ostlund et al. (1976)

cadmium in the upper 500 m, zinc at more than 1000 m, and nickel over a greater depth range. Copper, which increases in concentration with depth, is scavenged by fine particles in the deep water.

The input of some trace elements from the land or the atmosphere is small compared with the internal ocean fluxes and these elements must thus be recycled several times through the water column before being lost to the marine sediments. Their remobilization in the water column or at the sediment-water interface parallels that of the nutrients and organic matter which also re-enter the deep water column. The upward flux of all these substances is by the vertical physical processes which, as explained above, are relatively slow. The strong horizontal physical processes tend to reduce horizontal gradients during the return phase and help retain the overall similarity of the vertical profiles of most substances throughout the ocean basins.

Natural and man-made substances in the ocean are also carried by living organisms. For the most part the resulting transports are small compared with those by physical processes or particulate matter and have little effect on the overall distribution of the substances involved. In certain cases, however, especially when bioaccumulation occurs, biological transfers can result in bringing contaminants from the ocean back to man or some critical part of the ecosystem where its impact is important. In this context, one can note the case of DDT and the need to consider the possibility of the transfer of material from deep-sea dumping to man's food-chain.

II.5 The ocean floor

The sea floor serves as the ultimate depository for most of the conservative material that enters the marine environment, and this interface is a region of complex physical, chemical and biological activity. Microbial processes play a major role. Of the material which reaches the sea floor only a small part remains as accumulated sediment. Final burial may take place only after repeated recycling between deposition, remobilization, incorporation into particulate matter, and redeposition.

The sea floor includes the continental shelves, whose often broad, always relatively shallow, regions adjoin the land masses. Seaward, they drop off into the continental slopes that plunge to the great depths of the abyssal region. Much of the abyss consists of broad, flat sedimentary plains, but approaching the centre of the ocean basins a considerable part of the sea floor is covered by submarine sea mounts and deep-sea ridges. As the great tectonic plates of the earth slowly spread, new sea floor forms at the centre of the ridge systems. As it forms, very hot rock is brought from the earth's interior into contact with sea-water; this cools and cracks the new rocks; vigorous physical and chemical activity follows. Thus, active hydrothermal vents appear which have a profound influence on deep sea geochemical processes and represent major sources or sinks for many elements in sea-water. Associated with the vents are exotic communities of marine organisms whose primary food supply is based on the chemical energy emanating with the fluids. The vents represent intense sources of local chemical anomalies and can be used to improve our understanding of how contaminants would be distributed in the deep sea.

Except where the sea floor is very new, the deep ocean bottom is covered by sediments which have accumulated slowly, often over many millions of years. Principal sources of this sedimentary material include organic material created in the upper ocean and inorganic material of land-based origin. Slumping brings sediments from topographic highs on the continental shelves, effecting strong horizontal transfers, occasionally over large distances.

Material which reaches the ocean floor is altered by a variety of physical, biological and chemical processes, referred to as diagenesis, which may continue over millions of years. Chemical activity includes decomposition, dissolution, oxidation-reduction, adsorption-desorption, and authigenic mineral formation. The rate and nature of this activity are greatly influenced by the exchanges between the newly arriving material, overlying water masses and the sediment below.

Materials that return to solution and escape from the sediments are mixed by the bottom current systems. Usually a well-mixed boundary layer some tens of metres thick lies above the sea floor. In a thin layer, right at the floor, horizontal and vertical currents tend to disappear and molecular processes dominate, but over most of the boundary region strong vertical exchanges exist and horizontal transfers may be comparable to those in the body of the ocean. Mixing within the boundary layers around the edges of the ocean basins may provide the principle contribution to deep mixing across density surfaces. The removal of water from the boundary layer, which must also control the transfer of substances out of it, is probably intermittent and localized.

In the absence of faster processes, the material that is added to the sediments would simply bury material arriving earlier - average accumulation rates being a few millimetres per millenium. Chemical reaction products can then only diffuse through the sediments and the enclosed pore waters at rates controlled by molecular diffusion and adsorption-desorption processes. The increasing weight of overlying sediment tends to compact the deeper layers and reduce the pore-water fraction, causing some relative upward movement of pore waters.

Two exchange processes can disturb the slow accumulation of sediments. The first is simple resuspension of the near surface sediments in areas of relatively strong bottom currents. The resuspended sediment can then interact with the overlying waters. In some areas, a layer of suspended material - the nepheloid layer, may be several hundred metres thick. Newly arrived material may be partially mixed into the sediments and buried by this stirring process.

The second is bioturbation - the mixing of material by organisms living in the sediments. The benthic habitat is variable but for the most part consists of soft sediments. It supports a community consisting entirely of animals that depend for food primarily on the supply of detritus from above. Only between 1 and 3 per cent of the surface organic material is estimated to reach the bottom of the deep sea and to be available for this purpose. Although biological activity is most intense on the continental shelves, it can be significant in the deep sea. The infauna not only stir the sediment but may pump significant amounts of water into and through it, thus enhancing the exchange of pore waters.

Information on sediment mixing and accumulation rates has been obtained from observations of the profiles of natural radioactive tracers, such as carbon-14, thorium-230 and lead-210 or of anthropogenic substances such as plutonium-239.

While bioturbation and resuspension of sediments enhance the exchange between the upper sediments and the overlying water masses, final removal of a substance to the sediments is controlled by the much slower rate at which it can diffuse into the deeper sediments by molecular processes or by the net accumulation of sediments leading to burial. Bioturbation and resuspension can introduce an anthropogenic substance into the sediment relatively rapidly, and can enhance its removal from the overlying water mass or the very near surface sediments. But unless the substance then undergoes chemical or radioactive change it will, for the most part, be available for future interaction with the overlying waters and may, in some cases, act as a source for them later.

The nature of the sediment is affected by the rate and composition of arriving material. In the abyssal regions, where material arrives slowly, the sediments accumulate under oxidizing conditions and dissolved oxygen enters the sediments as rapidly as it is consumed by organic decomposition. Under regions of high productivity, or in shallower waters, more organic matter reaches the bottom. When decomposible organic matter enters the sediments at a rapid rate, decomposing materials significantly alter the pore waters; associated chemical changes are enhanced. When organic matter is abundant, microbes will consume all available oxygen, then turn to other substances. Under these conditions, hydrogen sulphide and methane are produced. From shallow sediments the latter can even lead to bubble formation and evolution. Redox conditions at and in the sediments influence the behaviour, remobilization and even toxicity of many contaminants introduced by man's activities.

Calcareous shells $(CaCO_3)$ are completely dissolved at the floor of the deepest ocean basins, but tend to accumulate in shallower waters. This distribution according to depth results from the effect of pressure which increases $CaCO_3$ solubility. Silica and calcium carbonate may accumulate on the sea floor, even where the adjacent waters are undersaturated, if the input rate of dissolving material exceeds the dissolution rate. In particular, dissolution must stop if pore waters become saturated, which occurs when the escape rate of the dissolution products is no greater than the dissolution rate of material. Proper understanding of the outcome depends upon a knowledge of reaction rates, input rates and the exchange mechanisms in the sediment and at the sediment water interface.

Siliceous or calcareous shells carry natural trace components to the ocean floor. These can be left behind, adsorbed on the residual clays, when the shells dissolve and disappear. Such pathways may also occur for contaminants.

Adsorption is an important phenomenon in diagenesis, significantly influencing the mobility and redistribution of materials entering the sediments. It is dependent on pH. Strong interactions exist between adsorbed organics and metals.

Authigenic mineral formation can occur at the sea floor, as shown by the formation of manganese or phosphorite nodules, both of which may become economically important, although the slow rate of nodule growth makes it very unlikely that nodules will incorporate significant quantities of contaminants.

As mentioned above, benthic organisms are instrumental in various biogeochemical processes occurring at the sediment-water interface. Their health depends on an adequate supply of uncontaminated food material. Adverse effects on the large scale would be difficult to recognize because of natural variability, but changes in the relative numbers of various trophic or taxonomic groups might be used to indicate stress by contaminants. Benthic animals, as accumulators of some substances, could be involved in pathways transferring contaminants from the deep sea.

II.6 Final remark

In the remainder of this report many situations are discussed where the scientific framework developed in this chapter has been implicitly or explicitly used to determine the state of contaminants in the marine environment. In many of these situations substantially increased understanding will only be possible through detailed studies of the processes involved.

CHAPTER III

BIOGEOCHEMICAL CYCLES

III.1 Introduction

The summary of oceanic processes given in the preceding chapter indicates the complexity of the ocean system and the need to consider the combined effects of physical, chemical and biological mechanisms when modelling cycles of natural and man-made substances. A balanced approach is required between (i) development of large-scale crude models for the biogeochemical cycle of various substances and (ii) investigation of the details of the processes affecting them. A classical, ecological approach could be employed using simple models at the level at which fundamental processes operate. These serve to develop an understanding of the dynamics of the system at grosser levels. For many substances, however, our knowledge of fundamental processes is inadequate to develop useful global or regional models.

To understand the biogeochemical cycle of a material, the environment is often divided conceptually into a number of compartments or reservoirs in which material is assumed to behave relatively uniformly. The behaviour of the substance is then described in terms of the interactions within each reservoir and the transfers between the reservoirs. The success of such an approach depends on being able to define reservoirs appropriately and on being able to give simple forms to the interactions and transfers.

Attempts to detail these interactions may include differing emphasis upon equilibrium effects or kinetic effects. In reality, biogeochemical cycles do not represent stable systems, but rather involve a constant series of perturbations including daily cycles, seasonal variations, effects of climatic shifts and random fluctuations. These keep the system in a constant state of readjustment which might be perceived and described on a wide range of time scales. In practice, most descriptions of biogeochemical cycles have emphasised the "steady-state" or time-average condition. These descriptions include, as far as possible:

(i) the nature and quantity of material entering the cycle from natural sources and from human activities;

(ii) the uptake by, and the concentrations in, the biota;

(iii) the principal conversion reactions that the material in the environment undergoes;

(iv) the role, with respect to biological systems, of the transfer processes described in chapter II.

Although our knowledge of these biogeochemical cycles is far from perfect, the quantitative descriptions provide models against which ideas and theories can be

developed and tested. These models offer the best available mechanism to guide decisions on the effects of pollution.

Man's effect upon a biogeochemical cycle involves relatively short-term changes in some reservoirs. This normally makes it necessary to take into account processes within the reservoir and perhaps to break down the reservoir into several parts. For example, the oceanic reservoir can be divided as described in chapter II. Although man's effects are relatively recent, their magnitude is not always small. Some of the man-made fluxes approach or exceed natural rates in the environment. Examples include: the release of carbon dioxide to the atmosphere by the burning of fossil fuel; the release of arsenic to the atmosphere through ore-smelting or burning of fossil fuel; the release of lead to the atmosphere through tetra-ethyl lead in gasolines; and the mobilization of cadmium by mining and industrial activities.

The cyclic movement of toxic elements in the environment is illustrated conceptually in figure III.1. Details of biogeochemical cycles are known in varying degrees of completeness for a number of elements and compounds. Most attention has been devoted to the major constituents of organic matter and to the more threatening pollutants.

In this chapter cycles are described (in differing degrees of completeness) for a nutrient element (phosphorus), and for two metals (mercury and cadmium). These are offered as examples of substances which may threaten the quality of our environment. The biogeochemical cycles have been under study for some time (e.g. SCOPE 1976, 1977, 1979; and Stumm 1977).

III.2 Metals

Wood and Goldberg (1977) divided metals of biological concern into three groups:

(i) light metals, normally transported as mobile cations in aqueous solutions (e.g., Na^+ and K^+);

(ii) transition metals, (e.g. iron, copper, cobalt and manganese which may be toxic at high concentrations and essential at low concentrations;

(iii) heavy metals or metalloids, that may be required for metabolic activity at low concentration, but which at slightly higher levels are toxic to the cell: e.g., mercury, selenium, lead, tin and arsenic.

Several factors must be considered in relation to the movement of metals in biogeochemical cycles: chemical form (solution, colloidal, particulate) and speciation; reactions with inorganic and organic matter (including biota); the magnitude of sources and sinks; and their location or distribution (Wood and Goldberg 1977).

Metals may be classified in terms of their relative toxicity and availability. Toxic metals forming organo-metallic compounds, like metalalkyls, are of special concern. These include mercury, tin, arsenic, selenium, cadmium and lead.

Man's activities also play a major role in the marine environment. The release of metals by man is most evident in coastal waters and shallow sea areas, as has been demonstrated in the Baltic and the North Sea (see chapter VI).
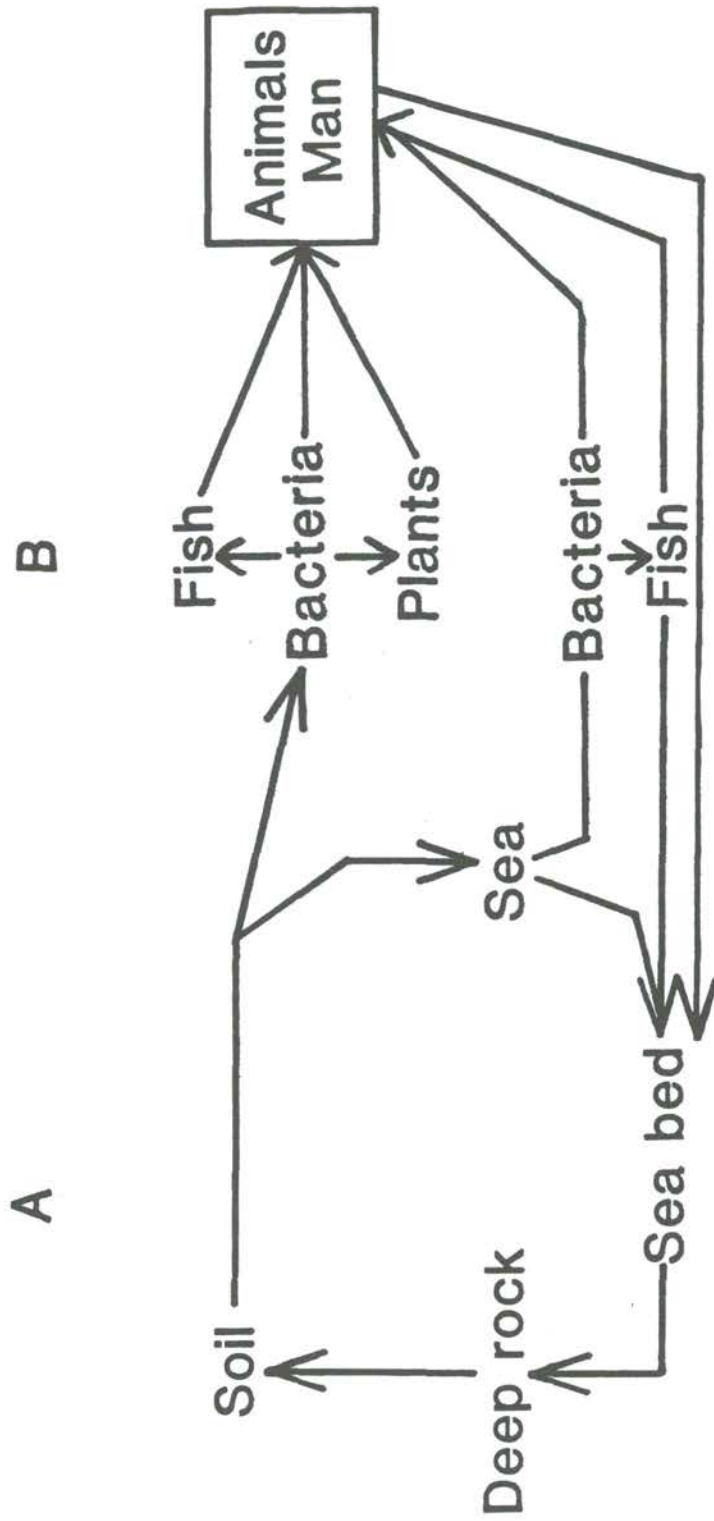
Figure III.1 : Movement of toxic elements through the geocycle. Figure taken from Wood and Goldberg (1977)

Mercury in the environment

Mercury has a low abundance in the earth's crust. It is not known to be an essential element for any species, but it plays an important role in man's activities. Industrial discharges of mercury at Minamata Bay led to one of the more serious marine pollution events on record (see chapter IV). At the time of that event (1956) it was commonly believed that mercury would be innocuous in the marine environment owing to its chemical properties. The Minamata incident showed that methylmercury can be a health hazard. Most industrial and natural inputs of mercury to the aquatic system are in the inorganic form, but following its release, inorganic mercury can be transformed to methylmercury. Methylmercury is the most hazardous form of mercury not only because of its high toxicity, but also because of its lipid solubility, which allows it to be accumulated rapidly within organisms, and leads to the possible accumulation in the food-chain. Figure III.2 illustrates the biogeochemical cycle for mercury.

The occurrence and use of mercury

Mercury occurs in rocks as the red sulphide, cinnabar, nearly pure HgS and in lesser amounts as the black sulphide and as the metal quicksilver. Mercury is also found in a number of minerals as a substitute for other elements, e.g., copper. The average abundance of mercury in the rocks of the earth's crust is in the ng/g range.

Man's activities generating emissions of mercury to the environment include combustion of fossil fuels, waste disposal, various industrial applications (most importantly from chloralkali plants), mining operations, the use of biocides, dental fillings, etc. It has been estimated that about 10,000 tonnes of mercury are released through these activities, of which 3,100 tonnes are from burning of fossil fuels. It has been estimated that man's activities have caused almost a four-fold increase in the flow of mercury from the land to the sea via rivers.

Mercury in the atmosphere

Owing to its high vapour pressure, mercury is circulated naturally in the atmosphere. Estimates indicate that 25,000-150,000 tonnes per year are released to the atmosphere by degassing from the earth's crust and from the oceans.

Mercury in the atmosphere exists predominantly (> 99 per cent) in vapour phase. The reported concentrations vary greatly ($0.5 - 50$ ng/m^3). Calculations of the fluxes of mercury from the atmosphere to the ocean are strongly dependent on assumed average values and also on the type of input process assumed. In one model of the biogeochemical cycle for mercury (NAS-NRC 1978) values of 1-2 ng/m^3 were used. Recent data give values of mercury in the atmosphere over the open ocean in the northern hemisphere of 1-3 ng/m^3, and 4-10 ng/m^3 over semi-enclosed seas like the Baltic, the North Sea and the Western Mediterranean (IAMAP 1981).

Even over urban areas the concentration may be only about 5 ng/m^3, but considerably higher concentrations may occur locally. Analysis of distribution data for mercury emission has shown that on the average only 20 per cent of the mercury is irreversibly bound after being deposited, while the rest is re-emitted to the atmosphere.

Mercury in soils

Mercury concentrations in soils cover an extensive range of 10 to 15,000 ng/g; for uncontaminated soils, the mean values are between 60 and 80 ng/g. In the terrestrial environment, mercury may occur in different forms, but mostly in
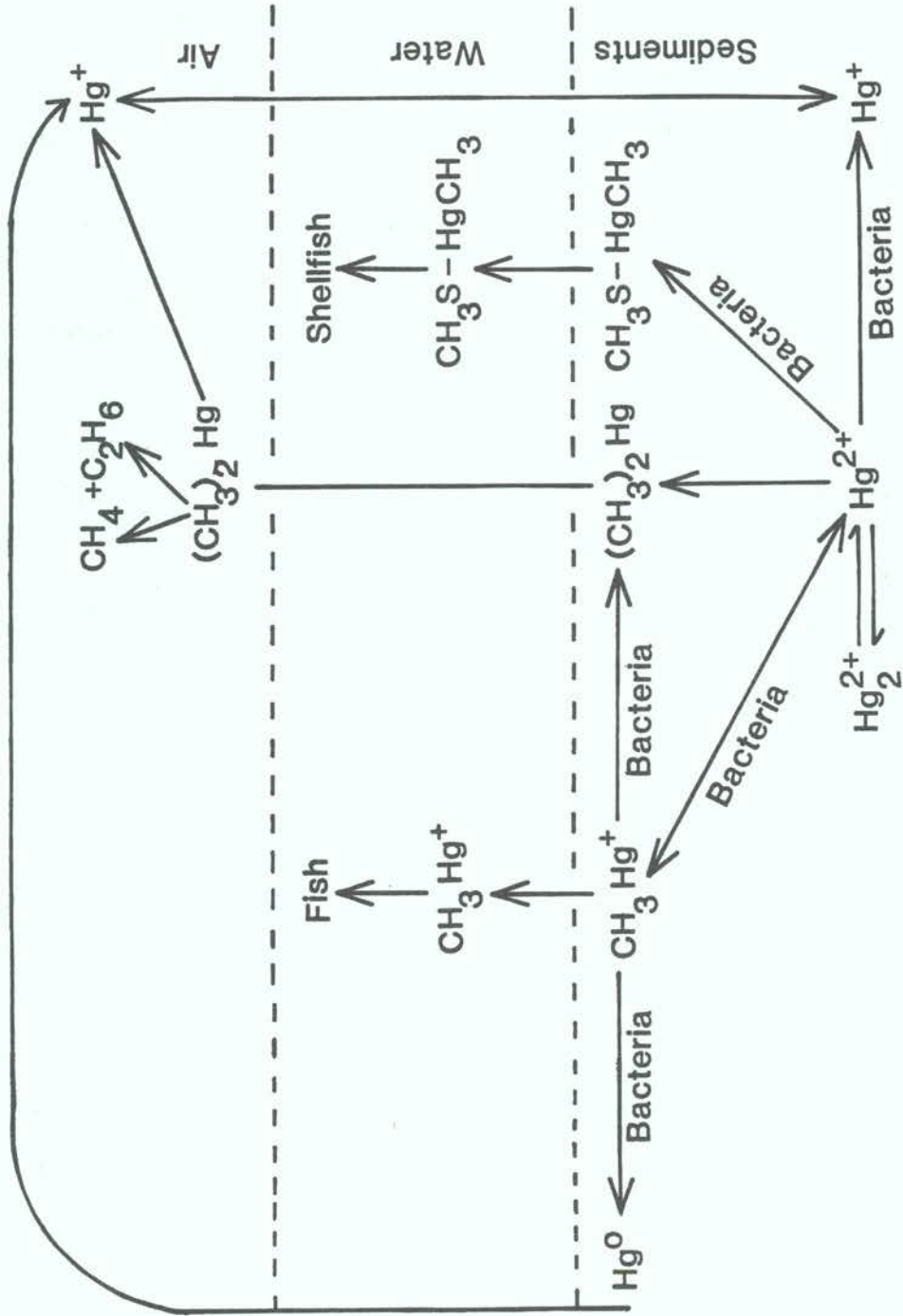
Figure III.2 : Biological cycle for mercury. Figure taken from Wood and Goldberg, 1977

complexes or associated with particles. The different forms all undergo transformation reactions such as methylation, de-methylation and reduction. Elemental mercury tends to vaporize and escape to the atmosphere.

Mercury in the aquatic environment

The concentration of dissolved mercury in fresh water ranges from 0.02 to 0.06 ug/l; oceanic values are from 0.001 to 0.01 ug/l. The mercury content of unpolluted freshwater sediments varies between 0.05 and 0.3 ug/g; whereas marine sediments show slightly higher levels.

In the environment, mercury may be present in different oxidation states both in the condensed phase and in the dissolved aqueous phase. The three inorganic forms are: elemental (Hg^0); mercurous (Hg_2^{2+}); and mercuric (Hg^{2+}) mercury. An equilibrium tends to exist between them. Metallic mercury occurs under anoxic conditions, but is rapidly oxidized in the presence of oxygen. Mercurous mercury undergoes disproportionation to metallic and mercuric mercury. It is also relatively unstable in the presence of biological material. Mercuric mercury forms stable complexes with inorganic and organic ligands, especially those containing sulphur and selenium. It forms strong complexes with halides, or may be hydrolysed. The predominant soluble inorganic mercury species will be either $Hg(OH)_2$ or $HgCl_2$ depending on pH and salinity. In the marine environment, the chlorinated mercury species predominate.

Soluble mercury species are to a large extent associated with particulate matter. Adsorption is affected by: the pH; the ionic strength; the amount and nature of complexing and adsorbing agents present; the redox potential; etc. Mercury is known to form stable complexes with a number of different types of organic compounds found in natural waters, such as sulphur-containing proteins and humic materials. Mercury has also been found to be strongly absorbed by plankton, and adsorbed by hydrated ferric and manganese oxides, and by clays.

Changes in the redox potential of the environment can affect mercury in two ways: by direct change in the oxidation state of the metal ion, as already mentioned, and by redox changes in available and competing ligands and chelates, or both. The sediment-water interface, where intense redox activity occurs, influences the behaviour of mercury in aquatic systems. Sediments with a high content of organic matter generally contain large quantities of reduced material - especially sulphides. Interactions in heterogeneous sulphide systems are important processes whereby mercury is retained in or released from the sediments. In anoxic sediments, mercury may occur as $Hg^0(aq)$, $HgS(s)$, $HgS_2^{-2}(aq)$ and methylmercury.

Mercury is mainly discharged into water as divalent inorganic mercury, or as the phenylmercuric ion. Biological and non-biological processes can transform all forms of mercury to methylmercury, thereby increasing the toxic effect of the metal. Microbial processes are particularly important. Methylmercury may also be microbially demethylated.

In unpolluted areas, mercury levels in aquatic biota are in the ng/g range. In polluted environments, the concentration may be several ug/g. Methylmercury may be biomagnified in the food-chain. High levels of mercury (several ppm wet weight) have been found in some top predators and in some of the biggest and oldest commercial fish species, even though many of these were taken far from polluted areas.

Transport in the marine system

In the coastal zone the major sources of mercury are from rivers, from waste

discharged through outfalls, and from wastes dumped directly into the sea. In estuaries mercury is affected by:

(a)   adsorption on to particulates;
(b)   deposition of particulates into sediments;
(c)   resuspension of sediments;
(d)   ingestion by organisms;
(e)   loss by volatilization;
(f)   transfer to the open sea.

Adsorption and deposition dominate, leading to an accumulation of mercury close to the input. Estuaries that act as sediment traps may serve as effective "sinks" for mercury.

From the sediment, biota can concentrate the mercury, but little attempt has been made to quantify the effects of this pathway back to the marine ecosystem at large. In one study it was estimated that 0.5 per cent of the total mercury in sediments was transferred annually to macro-invertebrates through feeding on bottom detritus and benthic algae; no methylmercury was detected in sediments or plants but 10-12 per cent of the total body burden of mercury in the macro-invertebrates was present as methylmercury. Body burdens of mercury in mussels reflect the concentrations in overlying waters and suspended materials in a contaminated estuary. Fish also reflect the level of contamination in the waters (ICES 1981).

In estuaries phytoplankton might remove as much as 20 per cent of the mercury annually but such losses would be hard to detect in the presence of other fluxes. Experiments show that volatilization losses are related to the amount of "reactive" mercury. In the presence of abundant suspended matter, most mercury will be adsorbed, and thus not "reactive", and accordingly volatilization losses should be small.

It has been calculated that no more than 1 per cent of the mercury in the upper 100 m of the ocean can be removed each year by phytoplankton (ICES 1981). The same investigation concluded that transfers associated with particulate matter must be an effective mechanism for removal of mercury, but less than 5 per cent of the mercury in the water column is lost to sediments over a period of 100-1000 years. Table III.1 shows the fluxes of mercury in open ocean reservoirs.

Cadmium in the marine environment

Information on fluxes and behaviour of cadmium in the marine environment has been summarized in ICES (1982), and the concentration ranges and fluxes presented are given in table III.2 and figure III.3. The global flux of cadmium to the ocean due to man's activities has been estimated to be about 50 per cent of the total flux to the ocean. The atmospheric deposition of cadmium is of the same order as the river input.

About 90 per cent of the suspended particulate material carried to the ocean through river run-off is sedimented on the shelf areas, which implies that only 10 per cent of the cadmium firmly bound to the particulate matter reaches the open ocean. But some of the "particulate" cadmium appears not to be firmly bound, rather it is remobilized from nearshore sediments, and eventually transported to the deep sea. Most of the cadmium entering the sea in dissolved form appears to reach the open ocean.

Biological processes greatly influence the distribution and transport of cadmium in the ocean. A remarkably strong relationship has been found between dissolved cadmium and phosphate. This reflects removal of cadmium during primary

Table III.1 : Fluxes of mercury within or into the open ocean
(modified from ICES 1981)

Compartment	Total Mass Flux	Conc. of Mercury	Mercury Flux (Tonnes/annum)
PLANKTON	50 g C/m^2/yr	0.05 ppm	1800
FISH	240 x 10^6 tonnes/yr	0.1 ppm	24
SEDIMENT*	4 x 10^8 tonnes/yr	0.1 ppm	400
RAINFALL	4.2 x 10^{17} litres	10 ng/1	4200
RIVERS	3.2 x 10^{16} litres	10-30 ng/1	320-1000

*Sedimentation rate taken as 1 mg/cm^2/yr.

	Volume		Total Mercury
SEAWATER	1.37 x 10^{21} litres	5 ng/1	6.85 x 10^6 tonnes

Table III.2 : Cadmium distribution in the environment (from ICES, 1982)

Phase	Concentration ranges	Comments
River-water*	10 - 100 ng/l	Considerable variability expected
Coastal sea-water*	10 - 200 ng/l	
Pelagic sea-water*	1 - 100 ng/l	Covariant with phosphate
Rain/Snow	10 - 1000 ng/l	Upper part of this range probably reflects pollution or sample contamination
Marine sediments	0.2 - 2.0 ug/g Average 0.4 ug/g	
Igneous rocks	0.1 - 0.3 ug/g	
Sedimentary rocks	0.04 - 4 ug/g	Excepting phosphorites that are heavily enriched in cadmium

* denotes dissolved.

The following diagram shows contemporary estimates of the annual fluxes (kg/a) of cadmium into and out of the ocean
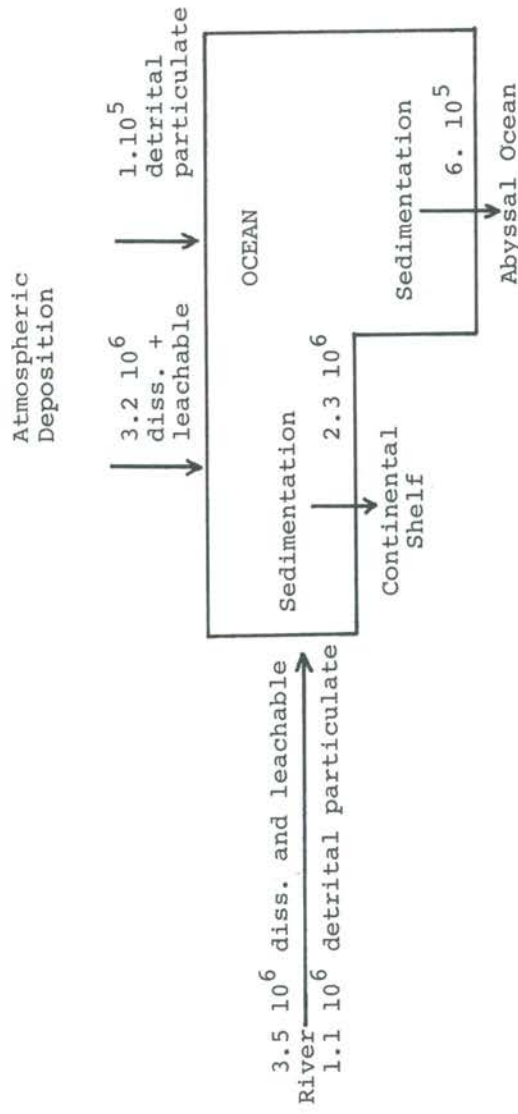

Figure III.3 : Fluxes of cadmium through the marine environment (from ICES 1982)

production and its release during decomposition of organic matter at rates closely corresponding to those of phosphorus. The residence time of cadmium in the mixed layer of the north-east Pacific has been estimated to be about 0.1 year. The supply is maintained by atmospheric inputs and by recycling from below due to vertical mixing. Detritus and faecal material sinking below the regeneration zone are sources of deep and bottom water cadmium. The removal of cadmium from the deep water column is not well understood, but it has been established that the flux of cadmium entering the ocean is greater than the measured removal from the water column to the sediments. Other known sinks for cadmium do not appear to be adequate to balance the marine budget. Thus, the cadmium content of the ocean may be slowly increasing.

III.3 Phosphorus

Man's activities also introduce vast amounts of the "nutrient" elements into estuaries and coastal waters. Nitrogen and phosphorus are of particular interest since shortages of these elements may limit marine productivity and their relative abundance can affect the species composition of the phytoplankton community.

SCOPE (1976 and 1977) has reviewed the biogeochemistry of these elements, and we focus here on the phosphorus cycle as a suitable example. Obviously the cycles of all nutrient elements are strongly interrelated.

Figure III.4 shows the reservoirs and fluxes. The atmosphere plays a minor role in phosphorus cycling. Soil and mineable resources represent major reservoirs, but the fluxes to and from these reservoirs are substantially less than the fluxes involving marine biota.

Within the sea, the phosphorus concentration ranges up to 0-4 umol/kg. It has a variety of inorganic and organic species. Generally, it is in short supply in upper waters, where it is needed to support growth, but is abundant in deeper waters where absence of light prevents primary production. As the flow chart (figure III.4) suggests, most of the phosphorus taken up in the near-surface waters by primary production is recycled to these waters as organisms are eaten and digested or die and decompose. But some phosphorus is continually lost to deeper waters as organisms and faecal material sink out of the surface zone. These losses are replaced by vertical mixing, upwelling, or fresh inputs from land.

Marine sediments represent an important sink for phosphorus, and marine phosphate deposits are a major source of our mineable deposits. Man requires large amounts of phosphate for fertilizers. Phosphate is also found in detergents, many industrial chemicals, and human and animal wastes. Fertilizer phosphates are retained in the soils to a considerable extent, but those in detergents and other sewage effluents are not. As a result, we have substantially elevated the levels of phosphorus in some coastal regions. In some rivers, lakes and estuaries the artificially high levels of nutrients have caused eutrophication leading to anoxic conditions, and enhanced concentrations in coastal waters may have other effects. Such eutrophication has not been found in open ocean waters.

Commonly the nitrogen/phosphorus ratio in sea-water is 15:1 (by atoms). This is very close to the average abundance of these elements in marine biota. It is not the ratio found in sewage effluents, however; these often contain 3:1 to 6:1 available nitrogen: phosphorus. Moreover, phosphorus tends to regenerate more quickly than nitrogen when organic matter is decomposing. These factors combine to cause a surplus of phosphorus compared to nitrogen in some coastal waters, so that nitrogen appears to be the main limiting element and therefore the one to watch in the context of eutrophication.
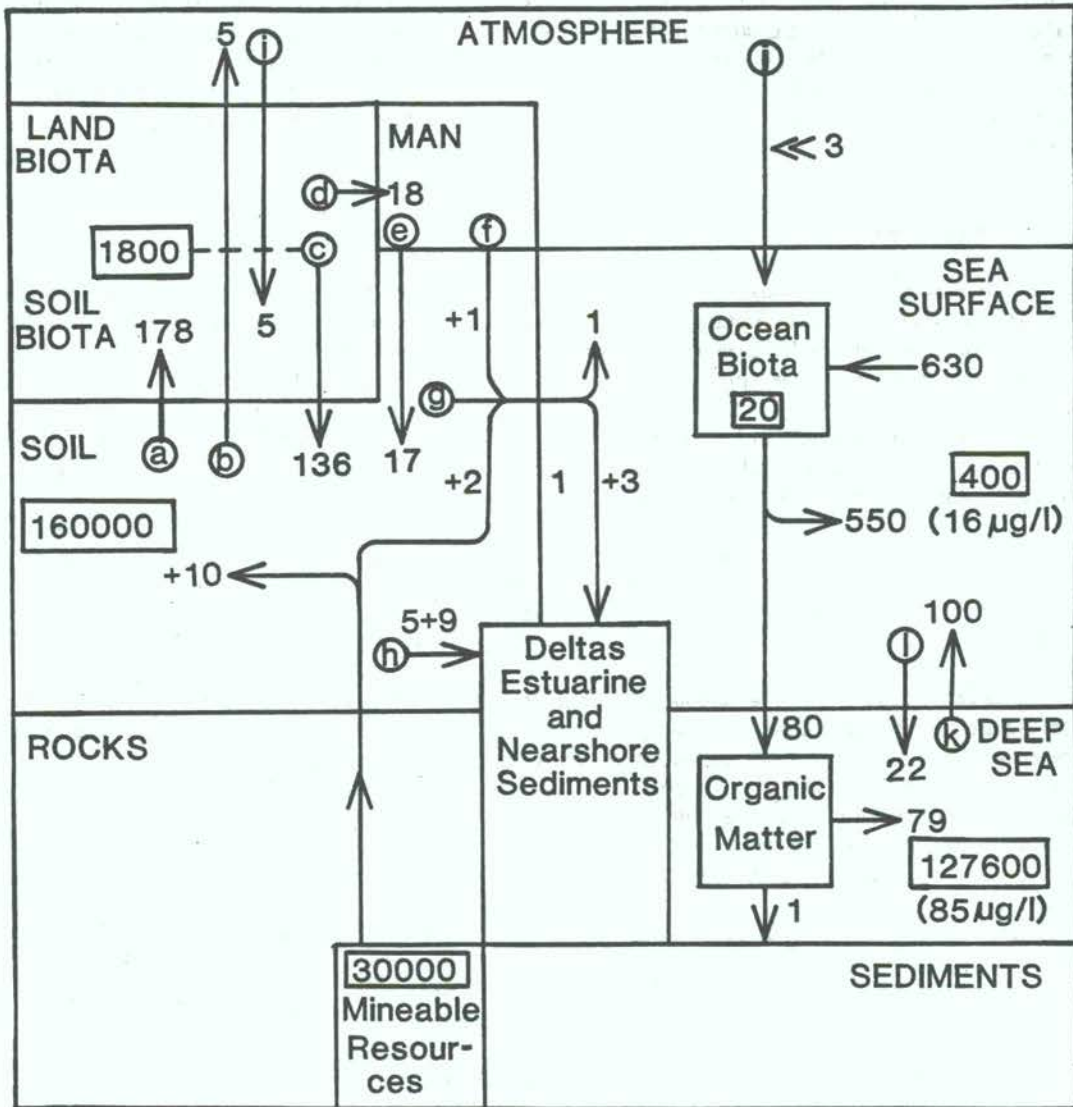
Figure III.4 : Preliminary global phosphorus flow chart. The units are Tg (million metric tons) per year (based on Pierrou 1976, in SCOPE 1976)

However, the increased phosphorus may also have an effect. Sea-water composition can play a very important part in altering the nitrogen/phosphorus ratio in phytoplankton cultures, and in changing the species composition of the phytoplankton community. Such alterations might be responsible for increasing the frequency of undesirable effects, for example, the red tides that can disrupt coastal waters (see chapter IV).

III.4 Concluding remarks

The example of the geochemical cycle of mercury described above together with studies of other elements undertaken by the Group, and published in the Technical Supplement (IOC, in prep.), enables certain general conclusions to be reached:

(1) Man-made sources have substantially increased the flux of many elements to the marine environment via the atmosphere, surface run-off and direct discharge.

(2) The increased fluxes to the marine environment (except via the atmospheric route) give rise mainly to increased local concentrations.

(3) Direct acute toxic effects may result from these increased concentrations, especially when they are accompanied by changes in local conditions. In extreme cases, these may give rise to local problems that may reach epidemic proportions, as for example, at Minamata, where the sequence of increased mercury flux, increased local concentration, and increased production of methylmercury, combined with a special human diet, has been unequivocably quantified.

(4) Chronic and other longer-term effects are more difficult to substantiate as occurring on any major scale in the marine environment, although specific effects such as the inhibition of enzyme metabolism by reaction of heavy metals with particular enzymes have been detected.

CHAPTER IV

PÓLLUTANTS IN THE MARINE ENVIRONMENT

IV.1 Introduction

A study of the health of the oceans requires consideration of many contaminants and potentially toxic substances. However, since time limited the field that could be covered, the group selected for this first report several contaminants that are at present particularly relevant to man's impingement on the oceans because of their distribution, quantity or impact. These contaminants are: sewage, some synthetic organics, petroleum, "trace metals" and radionuclides. This chapter reviews what is known of their effects on the marine environment. Other chapters in the report identify the mechanisms of transport of contaminants, their fluxes across critical interfaces, their distribution patterns, their biogeochemical cycles and the geographical areas where they have a major impact.

The statements presented here are supported by papers on each category of contaminant in the Technical Supplement; they refer to the basic literature and reports, and provide a more detailed scientific and technical discussion.

IV.2 Sewage

The word "sewage" is used here to refer to the product of municipal drainage systems containing domestic wastes with or without the addition of discharges from industry, storm water and surface run-off. Sewage is thus extremely heterogeneous, and its composition highly variable. It contains a large proportion of organic matter and nutrients, as well as numerous micro-organisms (bacteria and viruses, some of which are pathogenic) and parasitic worms. Oil and metals are usually present from a variety of sources and when significant quantities of discharges from industry are mixed with the domestic material, a wide range of additional chemicals may be included. There are several options for the disposal of sewage, including deposition on land and incineration, but, for coastal communities, sea disposal is clearly convenient. Sewage may reach the sea untreated, discharged directly into intertidal or subtidal zones by outfalls. However, various degrees of treatment may be applied before discharge, ranging from separation of solids and settlement of heavy particles followed by comminution, to chemical or biological treatment designed to break down organic matter and thus reduce the oxygen demand, producing an effluent rich in basic nutrients and probably containing soluble contaminants. As a result of treatment, sewage is divided into two phases - a liquid and a sludge - and these may be disposed of separately, the sludge sometimes being shipped to dumping grounds at sea. Marine pollution problems arising from sewage are therefore coastal and correlated with the distribution of human populations.

Ecosystem effects: The main impact of sewage from pipelines that discharge into relatively deep or well mixed water is in the immediate vicinity of the outfall where turbidity depresses phytoplankton production, and the benthic environment is altered by sedimentation. On the periphery, the effect is usually one of enhancement of biological communities by the input of inorganic and organic

nutrients. If the pipeline discharges on to the shore, growth of seaweeds and intertidal animal species adapted to high nutrient levels may be encouraged. Such enhancement of limited groups of species is one of the important effects of sewage input, which disturbs the energy transfer through food webs, eventually leading to greatly reduced species diversity. The impact can be considerable on some natural communities, such as coral reefs, or in low-nutrient habitats, where the long-established balance of species is easily upset. In general, however, treated sewage from a properly designed and well positioned outfall is unlikely to have a significant detrimental or beneficial effect over a wide radius.

When sewage sludge is disposed of at sea from dumping vessels the effects will depend not only on the rate and volume of dumping but also to a large extent on the physical characteristics of the disposal ground (see chapter II). In areas where the dumped material is rapidly dispersed by water movements and does not accumulate on the bottom, long-term effects are not detectable. Even on grounds where the material can accumulate, effects on the water column are usually transient, and it is only on the bottom that an impact can be clearly detected. Since sewage consists essentially of organic material and nutrients, usually along with potentially toxic components such as metals and organohalogens, eutrophication and toxic effects might be expected. However, although there is sometimes a build-up of toxic substances in sediments, adverse effects from this alone on the ecosystem have not been detected on dumping grounds, and the main changes can be attributed to organic enrichment leading to species-poor but often biomass-rich benthic communities. Only in the worst cases are the structure and condition of the sediment substantially altered, e.g. when deposition of organic material leads to anoxic conditions on the bottom and in overlying water, and the benthic macrofauna may be reduced to a few resistant species of worms. The most significant economic impact occurs when the habitat becomes unsuitable for benthic organisms of commercial importance, but even then mobile species such as fish and marine mammals, which are able to avoid unfavourable conditions, are not directly affected, whereas birds are attracted to sewage disposal sites and clearly thrive there. Finally, since the organic component of sewage is largely degradable, it cannot be regarded as a long-term contaminant if its introduction to the sea is properly controlled, and affected grounds may be expected to recover after the input ceases.

Human health effects: Visible sewage material on beaches and in shallow water can cause an offensive odour and a deterioration in amenities, but a more important consideration is the possible health risk. There is a continual flow of pathogenic bacteria, viruses and parasites into coastal waters around urban areas, reflecting the range of diseases that are present in the human population. These organisms can survive for hours, sometimes days, in the sea, and viruses can survive longer than bacteria particularly when they become attached to bottom organisms. In parts of the world where plumbing or drainage systems are ineffective or absent, faeces may be deposited directly on the beach, with obvious dangers of infection. Recent studies tend to support the assumption that bathing in sewage-contaminated water can result in disease, particularly in areas where the endemic enteric disease rate is high. Further, the consumption of fish and shellfish harvested from sewage-contaminated water can cause bacterial and viral enteric infections. Thus, when disposal of sewage sludge at sea is planned, the disposal ground should not be in an area from which water movements could transport sediment to beaches or shellfish beds. Treatment of sewage, particularly secondary treatment with chlorination, can substantially reduce the bacterial numbers but viruses are less affected. Chlorination can, however, give rise to increased quantities of chlorinated organic compounds.

Discussion: The evidence suggests that, given the controls outlined below, it is possible to dispose of sewage at sea so that it does not constitute a threat to

the marine ecosystem. Although there are "hot spots", these are usually restricted to a few square kilometres adjacent to outfalls and on sludge dumping grounds. A public health risk from infections exists on some bathing beaches, especially to visitors from other countries who have low levels of immunity to the local endemic diseases, and the discharge of untreated sewage on shellfish beds can pose a threat of more serious diseases. The volumes of sewage to be disposed of are greatest where the highest population densities exist, but problems that arise are at present local rather than global, and coastal rather than oceanic. Over-enrichment of some coastal waters through excessive nutrient input has led to extensive blooms of algae, some of which are toxic to fish and other marine organisms, and sometimes to human consumers. However, if the disposal of sewage to the sea is adequately controlled and if the sites are properly selected so that the assimilative capacity of the environment is not exceeded (see chapter VII), then the fertilizing nature of sewage may be regarded as more significant than its potential toxicity. It is worth noting that full treatment of sewage is not necessarily the optimal procedure. Indeed, where deep water is available close to the shore, disposal through long pipelines after minimal treatment may be satisfactory. Fortunately, there is increasing awareness, at local and national levels, of the problem of sewage disposal and the establishment in recent years of various international conventions provides mechanisms for controlling discharges and for documenting effects.

IV.3 Organochlorines

This section deals with only two of the most widely used organochlorines - PCBs and DDT.

Polychlorinated biphenyls

PCBs consist of a large number of homologues and isomers of chlorinated biphenyls. The number of chlorine atoms per molecule varies from 1 to 10. Polychlorinated biphenyls can be used for a wide variety of purposes and the mixtures of isomers produced by the various manufacturers may range from those containing about 20 per cent by weight of chlorine, averaging about one chlorine atom per molecule, to some containing about 60 per cent of chlorine, with different percentages of chlorinated biphenyls with 3 to 6 chlorine atoms per molecule. The physico-chemical properties of the mixtures, as well as their toxicity to living organisms, vary widely, being related to the actual amount of the several isomers.

PCBs are widespread in surface waters and bottom sediments in the more industrialized regions of the world. Being transported to the open ocean mainly by air, their ultimate sink is the marine sediments where they are adsorbed and only very slowly released to the water column and living organisms. Recent investigations indicate that marine micro-organisms can transform PCBs, but the process is very slow.

In organisms the highest levels of PCB residues occur in or near urban and industrialized areas. In fish, values of less than 0.1 ug/kg wet weight (1 ug/kg extractable fat) are reported from unpolluted areas but where there are large PCB inputs, residues are well above 1 ug/kg wet weight, and values up to 300 mg/kg extractable fat have been found. The level of residues is often related to the organism's position in the food-chain, but this is not always the case and care must be taken in extrapolating data. The isomers with three or fewer chlorine atoms are metabolized slowly and this leads in most species to progressively higher levels in the food-chain of the tetra-, penta-, hexa-, hepta-, or octa-chlorobiphenyls. Monitoring studies suggest that PCB residue levels in some areas are decreasing, following the restriction of their use in several countries (OECD, 1980), but the rate of disappearance seems to be slow, and is not firmly demonstrated. In many

areas, however, although inputs are known to have decreased, residue levels are stationary or increasing, presumably being derived from accumulation sites.

Ecosystem effects: For fish and other marine organisms the acute toxicity is higher for mixtures with a low chlorine content and there is a cumulative effect. The values of lethal concentration for rainbow trout range from 38 ug/l (Aroclor 1248) to 326 ug/l (Aroclor 1260) for a 10-day exposure, whereas for a 20-day exposure the LC50 (the concentration that kills half the test animals) for the same mixtures are respectively 6.4 ug/l and 49/ug/l. Fish are more sensitive in the early stages of life, and the same applies to marine invertebrates which are, as adults, more sensitive than fish.

Several effects of PCBs in marine organisms have been identified and described from laboratory studies. At high concentrations, these effects range from mortality to retardation of growth, impairment of reproduction in fish and invertebrates, increase in fish thyroid activity and reduction of natural compensatory reactions to stress and diseases.

In mammals, it has been suggested that PCB ingestion may lead to disturbance in the sexual functions and recently reproduction defects in seals in the Baltic and Dutch Waddensea have been linked with high PCB levels in the parents.

Marine organisms, including fish, can take up PCBs from water and from the ingested food. The relative importance of the two uptake routes in nature is difficult to assess solely from analysing field samples; hence, environmentally-determined concentration factors reflect PCB input from both routes. However, with carefully designed laboratory experiments, PCB accumulation from water and from food can be separated and the relative contribution from each route assessed under a given set of conditions. This information can then be applied to field data and estimates can be made of the relative importance of PCB input via food and water under natural conditions.

The accumulation of PCBs, like that of other organic compounds, is directly related to their lipid solubility and resistance to enzymic degradation, and inversely related to their water solubility. The main in vivo metabolic process is hydroxylation, converting PCBs to water-soluble phenolic compounds, which are eventually excreted. The rate of hydroxylation depends on the activity of enzymes (the hepatic microsomal mixed-function oxidases), which is very low in fish (in contrast to mammals) and decreases with increased chlorination of the contaminant. The dependence of this reaction on chlorination explains why only the metabolites of the lower chlorinated PCBs can be identified in fish, and why clearance half-times generally increase with the degree of chlorination. However, bioaccumulation is not clearly correlated with the number of chlorine atoms since metabolism is only one of the relevant factors.

Human health effects: Since man is one of the species most susceptible to PCBs (WHO 1976), residues in marine organisms used as food could represent a public health problem. Some countries have imposed concentration limits for the residues, and if these values are exceeded, the sale or importation of the contaminated seafood is banned. However, there appear to be no confirmed records of illness from this source.

DDT and its metabolites

DDT is the best known example of a persistent synthetic organic chemical. It and its main metabolites (DDD and DDE) are relatively stable under environmental conditions, highly lipophilic, and resistant to complete breakdown. DDT has been

the most extensively used pesticide on a global scale and, in 1974, world-wide production was around 60,000 tonnes. It is applied in forests and to almost every type of agricultural cropland, as well as for public health protection. It is widely used at present in developing tropical countries but in northern latitudes has been restricted for ecological reasons and because tolerance by insect species has developed.

DDT has been detected in rain-water, in Antarctic snow, and in soils and lakes far away from areas where it is used. Like PCBs, DDT is transported in the atmosphere and in water courses. It cycles in the food web and can be magnified in certain food-chains. The ultimate sink of non-degraded residues is the marine environment. There are still gaps in knowledge of the circulation and fate of DDT and its analogues in the environment as a whole. Degradation and metabolism seem to be influenced by sunlight, temperature and humidity, possibly leading to higher rates in tropical climates with formation of several still unknown metabolites. Very little is known of the toxicological properties of these conversion products (except for the major metabolites) and this has to be kept in mind when evaluating effects. However, it should be noted that even less information exists on the environmental fate of many other pesticides, including those that are now being substituted for DDT, such as toxaphene, which is used, for example, in cotton-growing areas. Residues of this pesticide, which is a mixture of chlorinated compounds, are being reported in marine fish far away from where it is applied.

In view of the large amounts that have been used, and recalling the persistence and stability of DDT, it is not surprising that its residues are now found widely in samples from the natural environment.

Ecosystem effects: Concentration of DDT in living organisms may be the result of absorption from water, of the filtering out of micro-organisms or detritus containing the compound or of biological concentration through the food-chain. Residues in animals show a dynamic equilibrium related to intake so that there is an increase or decrease depending on levels of exposure. Accumulation and detoxification rates vary widely between species. The highest concentration factors (residue in the organism divided by residue in its environment or food) of about 70,000 have been recorded for molluscs such as oysters and clams, while for fish or crustaceans these factors are 10^2 to 10^4. Sea-bird concentration factors are lower, approximately 10 or less.

Residue levels of DDT and its metabolites range widely depending on the species of organism and on the sampling location. The highest values have been reported in fish-eating birds from North America and Europe. Most of the information for the marine environment relates to coastal areas, though the few published results on species from the open ocean show that DDT and its metabolites, as well as PCBs, find their way to the deep-ocean species. Residues in fish muscle from coastal areas have been reported in the range of 0.01 to 10 mg/kg (wet weight) and are higher than in similar species from the open ocean. Residues in fish tissues differ greatly from organ to organ and the solubility of DDT in fat is well illustrated by the high residues in fish oil and adipose tissues.

Residue levels of DDT in sea-water are usually much lower than 1 ng/l but higher values have been reported from coastal areas. Residues of DDT and other organochlorines in birds are primarily related to food intake, although species differ in their ability to absorb, concentrate and metabolize chemicals. Fish-eating birds usually have higher residues than those species that eat seeds or vegetation. In view of the higher levels present in freshwater or estuarine fish, birds preying on these species have higher levels than those feeding on marine fish. In evaluating effects, it must be recognized that chemical changes of organochlorine

insecticides within the animal body may drastically alter the toxicity and storage of the parent compound.

The most important effect is in birds - eggshell thinning caused by interference with calcium metabolism. This has been recorded for marine birds in which magnification of residues in the food-chain occurs. Marine organisms show large differences in sensitivity to DDT. Thus, for zooplankton, the lethal concentration starts at 0.01 ug/l; for fish (including fry) 0.1 ug/l is toxic; phytoplankton, crustaceans and molluscs are affected by concentrations above 1.0 ug/l. However, as the ecological impact may depend on the most sensitive species, the margin of safety is not more than a factor of ten at concentrations of 1 ng/l.

Effects of high residue concentrations due to continuous or repeated exposure have been detected in marine animals. Mortality may occur after some time even if the fish are transferred to clean water. Reproductive success is low when residues in the fish eggs and fry are high (ppm level) and when the adult spawning fish has high DDT in the diet. Organochlorine insecticides, being lipid-soluble, accumulate in eggs and can lead to death of larvae as the yolk sac is absorbed at a critical stage of growth. DDT residues at sublethal levels may also affect behaviour and the capacity to react to external stress such as water temperature changes. Laboratory studies and field observations show that deleterious effects may be caused by DDT, but most of the effects identified so far have been related to residue levels much higher than those found in the open ocean, either in water or in fish food organisms.

Human health effects: It is unlikely that tolerance levels for man will generally be exceeded by consuming marine food, but there is the risk that in some coastal zones, residue levels are being reached in some marine organisms which might make them unacceptable as human food.

Discussion

Although general trends in the environmental concentrations of chlorinated hydrocarbons are apparent, there are still problems in comparing the concentrations reported by different authors, particularly in the case of concentrations of PCBs in sea-water. As the analytical problems become better understood, it is clear that an adequate assessment of the impact of organochlorines on the marine environment requires further study of their transport and fate, particularly their mobilization from sediments. If the environmental pathway of PCBs can be quantified this could be used as a model for other persistent chemicals.

IV.4 Petroleum

Pollution by crude and refined oil arises from tanker accidents, deballasting operations and tank washing, refinery effluents, municipal and industrial discharges, losses from pipelines and offshore production. Oil also enters the sea from natural seepages. The input of petroleum to the marine environment from all sources is thought to range from 2 to 20 million tonnes per annum, with the best recent estimate around 6 million tonnes, about one-tenth of which is probably from the atmosphere.

Oil from rivers and terrestrial run-off poses a problem in the assessment of biological effects. Most of it reaches the coast in a comparatively dilute form, adsorbed on suspended material, and it has been subjected to weathering so that part of the more acutely toxic compounds has been lost. On the other hand, in the estuaries where it meets the sea, most of this suspended material is deposited and

such areas are frequently important breeding and feeding grounds for a variety of marine organisms. Oil entering the ocean directly from spills is immediately subject to a variety of physical, chemical and biological processes which determine its distribution and fate. Following a spill, spreading and evaporation, along with photochemical and other oxidative processes, are important for the first few days. After this, degradation by micro-organisms becomes significant, particularly for the paraffinic and olefinic fractions. It should be noted that marine bacteria are not capable of completely destroying hydrocarbons. Thus, some oil components (e.g. PNAHs) are oxidized to a form which is no longer amenable to further bacterial breakdown, although bacteria can destroy up to 50 per cent of such molecularly stable compounds as benzo(a)pyrene (Izrael and Tsyban 1981). Even for those fractions of oil which can be degraded by micro-organisms, adequate oxygen and nutrients are required.

Particles of oil residues of varying size and density are distributed throughout the oceans, mostly on the sea surface. Some are formed soon after oil is discharged by tanker washings, others materialize over a longer period of time in the sea from weathering of spilled crude or heavy oil products. One recent estimate of the particulate oil residues on the surface of the North Atlantic was between 15,000 and 20,000 tonnes. The level of contamination is closely connected with tanker traffic and other shipping. This was shown by a project which arose from the 1972 Stockholm Conference, the Pilot Project on Marine Pollution Petroleum Monitoring (MAPMOPP), which comprised a study of surface slicks, floating tar, dissolved/dispersed petroleum residues at 1 m depth, and tar stranded on beaches. Further work suggests that petroleum films on the sea surface could contact and concentrate other oleophilic contaminants such as organochlorines and organic forms of trace metals. These have been detected and measured in tar balls (Sunay et al. 1979).

Petroleum is a complex mixture of compounds with different physical and chemical properties, and special attention must be given to the collection of samples if they are to be representative and uncontaminated. There is no single method for the analysis of total oil which would be acceptable in all situations. It should be noted that hydrocarbons are synthesized by living organisms, and that the components of this biotic production are very different from those of petroleum that cause concern - light or polycyclic aromatic hydrocarbons, light alicyclics, heterocyclic nuclei and their alkyl derivatives which are not known to be produced through recent biosynthesis. Biotic production of alkanes greatly exceeds the petroleum discharge into the sea, and it is important to be aware that some analytical methods lump hydrocarbons from the two sources.

Ecosystem effects: Marine organisms absorb oil, but there is little convincing evidence of accumulation or biomagnification. In general, organisms from higher trophic levels show lower concentrations of hydrocarbons. Effects on the ecosystem include those arising from toxicity and from smothering and clogging. Lethal effects and habitat destruction may have long-term ecological impact but, except perhaps in some bird species, whole populations are seldom at risk. Assessment of environmental effects is based on observations of numbers and species of organisms killed or obviously damaged by oil discharges, coupled with laboratory measurements of toxicity through bioassays. Toxicity is largely associated with the aromatic-hydrocarbon content of the oil, although for some organisms the non-hydrocarbon components are most toxic. In addition to their acute toxic effects on marine life, crude and refined oils affect marine organisms at concentrations that do not result immediately in death. Included in these chronic effects are interference with feeding and reproduction, abnormal growth and behaviour, susceptibility to predation, and interference with chemical communication between animals and with the chemical senses used in migration. These effects can lead to changes in the abundance and distribution of individual species and to shifts in

species composition within the oil-affected area. A great number of factors, acting individually and in combination, govern the effects that an oil discharge may have on marine life. In general, the biological damage is more severe if the discharge occurs in a coastal or estuarine environment rather than in the open sea, especially if the intertidal zone is affected. The special circumstances of the polar regions must be recognized. As a result of low temperatures in these areas, degradation of oil is slow and organisms are exposed to toxic fractions for longer periods. Laboratory tests of acute toxicity provide little help in making accurate predictions of what happens in the field, partly because the simplicity of laboratory systems as compared with the complexity of marine systems can give rise to exaggerated results. However, the study of populations in large controlled enclosures has attempted to bridge this gap (Davies and Gamble 1979).

Sea birds are one group of marine organisms that have been affected by oil pollution at least to an extent sufficient to jeopardize local populations, but even in this case it is difficult to correlate overall population trends with pollution because of the natural variability of ecosystems. Extensive effects on marine mammals due to oil pollution have seldom been reported. Crude and heavy fuel oils do not seem to cause widespread mortalities of adult fish except in shallow, enclosed waters, but light and refined oils are more damaging. The use of fishery statistics to demonstrate the effects of oil is difficult, owing to the potentially great number of unknown factors, economic and ecological, which could influence the data. However, where adequate pre-spill information exists, this approach can be useful for localized spillages or discharges. Subtidal and intertidal benthic organisms have suffered particularly heavy losses from accidental spillages of oils and from their treatment. Complete recovery of affected populations may take years or decades and repeated oilings are particularly damaging. Destruction of marine grazing animals upsets ecological balance and this type of secondary effect has to be considered when damage due to oil is evaluated.

The introduction of oil hydrocarbons to the marine environment favours the bacteria capable of utilizing this food source at the expense, at least initially, of the rest of the population, and the number of carbon-degrading micro-organisms increases from clean to oil-contaminated areas. Susceptibility of micro-algae to oils varies enormously. Laboratory studies show that higher concentrations lead to reduction of carbon fixation, arrest and finally mortality, but the growth of many micro-algae is stimulated by very low concentrations of oil. Macro-algae, if coated with oil, may be more easily stripped from their substrate mechanically. Some are resistant to oil and thrive in polluted environments, while low concentrations of oil have been shown to depress the growth of others. Oil penetrates the higher forms of plant life, blocking intercellular spaces, increasing respiration and reproduction. Some littoral or salt-marsh plants may tolerate repeated light oilings but heavy fouling often leads to mortality, although these effects may take several years to appear.

Oil slicks at sea kill or adversely affect zooplankton, including totally planktonic species like copepods, as well as the planktonic eggs and larvae of fish and benthic invertebrates. Copepods are an important component of marine food-chains and it has been shown experimentally that their population levels can be reduced by oil at concentrations found in the immediate vicinity of offshore platforms (ICES 1980a). The possible long-term effects of this in the sea have yet to be assessed. Eggs and larvae which occur near the sea surface are particularly exposed, and are sensitive especially to light oils, but it is unlikely that the mortalities from a single spill would affect more than one year class of adults, and even then the natural variability in year class strength is such that effects would be difficult to detect, as illustrated by at least one study of commercial fish populations (ICES 1977a). In all these cases of effects on zooplankton, the

long-term or ecological significance is not clear. In general, effects of oil should be studied at the ecosystem level, rather than by single-species bioassay. Attention should also be paid to chronic and sublethal effects, using, for example, histopathological techniques, and to genetic alterations and other effects on species in the field.

Human health effects: These are considered under the headings of carcinogenesis and tainting.

Carcinogenesis: Polynuclear aromatic hydrocarbons (PNAHs) of known mammalian carcinogenicity occur in crude and, particularly, in refined oils. Reported levels of named compounds, such as 3.4 benzpyrene and 1.2 benzanthracene, vary widely from 0.005 ppm to over 3 ppm, but the residues from catalytic cracking and pyrolysis may contain over 1000 ppm. Compared with other sources, oil does not provide a significant proportion of the PNAH input to the marine environment on a global scale, but can be a major contributor locally, particularly in sewage discharges and refinery effluents. There is a substantial input of PNAH to the sea via the atmosphere as fall-out from the combustion of organic material, but this is globally distributed and the concentration is low. Relatively high levels of PNAHs can occur in living resources, especially in molluscs and algae, and these high levels are frequently, but not necessarily, associated with known sources of terrestrial pollution, including oil. The accumulation of PNAHs in marine produce raises two public health questions: Do they present a cancer risk to the consumer, and do they combine with other carcinogens of non-marine origin and increase the risk of additive or synergistic effects?

The concentration of PNAHs in marine organisms depends not only on uptake but also on the ability of the organism to store and metabolize this group of compounds. There is a greater storage and persistence of aromatics and PNAHs in lipid-rich than in lipid-poor fish and, within one species, more PNAH accumulation in lipid-rich than in lipid-poor tissues. Fish and crustaceans can metabolize PNAHs and excrete them as the more water-soluble hydroxylated products. Molluscs are less able to do this.

Marine fish and shellfish tend to concentrate PNAHs within their tissues when exposed to oil but do not retain these levels indefinitely. Initial rates of PNAH elimination are high, but some 1 to 10 per cent of the intake remains after a period of days, which may still be 10-30 times the background level and which is discharged only slowly, if at all. The slow rate of discharge of the remaining 1 to 10 per cent hydrocarbons, particularly in shellfish, provides a potential for accumulation by predation, but this has not been documented. There is evidence that molluscs do not depurate oil hydrocarbons which have been slowly concentrated under chronic conditions as quickly as those acquired from acute, if temporary, elevations of ambient concentrations. Molluscs accumulate PNAHs to higher concentrations than any other marine organisms, but as these shellfish form only a very small part of the total human diet, their importance as contributors to carcinogenic risk might be small. The risk is further reduced because PNAHs have low gastro-intestinal absorption. While there appear to be no epidemiological studies that link gastro-intestinal cancers in man with PNAHs or other oil constituents accumulated in commercial species of marine fish or shellfish, there is evidence that the frequency of stomach cancer is significantly increased when the diet is dominated by smoked fish (e.g. in Iceland and Newfoundland) enriched with PNAHs by the smoking process. Thus at present it seems reasonable to suppose that PNAHs accumulated from the environment in marine produce do not cause cancer without additional exposure, although they may add to the risk presented by all other sources. Medical and toxicological consultations are needed to: (a) assess the degree by which PNAHs in marine products increase the carcinogenic risk by an additive effect and (b)

evaluate the extent of the shift in the total exposure towards or above the threshold for cancer caused by marine produce. These considerations can help to set any PNAH levels above which a fishery should be closed and which must be regained by depuration in the field or under transferred stock-holding conditions before such produce could again be made available for consumption. Medical consultants in the field of experimental carcinogenesis should review the evidence and prepare evaluations and conclusions, recognizing that the necessary experimental data, such as histopathological and detailed chemical analysis and their correlations, are only now becoming available. Such a task must include a decision as to which "indicator" PNAH compound, or spectrum of compounds, should be measured, and by which methods, in a sample of produce suspected of contamination. This leads to the important consideration of the relationship of oil "taint" to PNAH levels in tissues. Taint in itself may be a reason for rejection of produce but its presence or absence is not necessarily an indication of the PNAH levels. The concentration of selected carcinogenic PNAH compounds or assemblages must be determined by direct analysis. These levels should form the basis for closure or re-opening of a fishery or the release for consumption of marine produce that has been affected by oil pollution, but which has subsequently been transferred to cleaner waters.

Tainting and loss of marine foods: The extent of losses due to oil pollution has been impossible to evaluate owing to inadequate documentation of incidents, claims, closures or condemnations of produce. However, there are examples of produce being rendered unacceptable on the grounds of altered appearance, and of the closure of fisheries on the grounds of officially determined health risk, and most of the information refers to tainting, that is, to the presence of an unpleasant smell or flavour. It was established that: (a) crustaceans, fish and molluscs exposed to oily conditions can acquire an oily taste; (b) the taste is intimately associated with the presence of volatile compounds derived from oils or dispersants; (c) the range and quantity of odorous compounds vary with the nature of the oil.

Exposure to oil can initiate or promote the spread of some disease organisms in marine fish although such diseases can also occur in areas unpolluted by oil. Serious losses of produce could arise in this way, owing to mortality or unmarketability, but no proven instances are known. When contaminated organisms are placed in clean water, some of the accumulated oil and oil components can be eliminated. The use of dispersants facilitates the uptake of oil by organisms, and the use of oil-based dispersants increases the likelihood of flavour being affected, since the solvent fractions of older dispersants contain tainting compounds similar to those found in diesel and crude oils. External contamination with oil does not necessarily impart a taste to flesh, although visible external contamination may in itself be a reason for rejection of produce. Even ingestion of oil by marine organisms does not always taint the flesh, but some species of crustaceans and molluscs are consumed together with their gut contents, which may lead to rejection of produce. Cooking of whole animals that have been internally or externally fouled with oil may lead to tainting of the meats. There have been too few studies on the tissue levels of oil components in affected produce for tainting threshold levels to be established firmly. A threshold of 10-30 ppm in tissue spiked with a North Sea crude oil has been reported, with an upper limit of 200-300 ppm, beyond which no further increases can be sensed by a trained taste panel. Threshold levels of 5 ppm gas oil in spiked mussel tissues, and 4-12 ppm extractables from diesel oil in lobsters have also been reported. Exposure to ambient water concentrations as low as 0.01-0.02 ppm oil can lead to tainting of meats. The collated evidence illustrates the impossibility of using the paraffins to predict the behaviour of the aromatic fraction of oils in water and tissues. The possibility of selective uptake and accumulation of PNAHs with their homologues needs examination.

A more extensive discussion and literature review is provided in a report of GESAMP (1977a).

IV.5 Metals

The terms "heavy metals" and "trace metals" are used very loosely. They include a wide range of elements which are not all "heavy" metals, or even metals. The concept of toxicity is usually associated with these terms and the following elements are included: Hg, Cd, Cu, Zn, Co, Mn, Mo, Ni, Pb, Fe, As, Al, Cr, Sn, Ti, V, Ag, Bi, Be, Se and Te. From this list the present report deals in some detail with mercury and cadmium.

As discussed in chapter III, trace metals enter the ocean as a result of natural processes and human activities via rivers, land run-off, dumping, the atmosphere and the sea bed. Major natural sources are rock weathering, degassing, releases from terrestrial and submarine volcanoes and dissolution from marine sediments. The dominant inputs for most trace metals are through river and land run-off, but for a few elements, such as mercury and lead, the atmospheric route is important, particularly in the open ocean, although even for these elements local discharges and rivers can dominate the coastal input because delivery is from a point source.

As in the case of other pollutants the accuracy of trace metal analysis is also uncertain. Recent changes in the sampling techniques and in the analytic procedures have shown that open-ocean water concentrations are much lower than previously thought (ICES, 1980b). Also the concentrations of cadmium and lead in unpolluted biota are lower than previously reported. In nearly all cases these low levels are many orders of magnitude below the levels at which effects on biota would be expected, although in the coastal zone especially near waste releases, toxic concentrations are reached.

When introduced into the sea, some trace metals do not remain in the water column. They may be concentrated in the surface film, or become adsorbed to suspended matter so that they sediment out on the bottom (see chapter II). Although sediments are sinks, the trace metals may re-enter the water column by various physical, chemical and biological processes. In this way, the sediment serves as a buffer and may be able to keep the metal concentration in water and biota above the background levels long after the input has been discontinued. The geological distribution of individual trace metals and consequently the regional inputs to the environment are not uniform. Environmental levels are usually high around non-exploited metalliferous areas and even higher round mines where waste discharge adds to the weathering effect. The contamination of the Fal estuary in England by copper and zinc through mining waste discharges; the increased copper levels in water, sediments and biota (165 mg copper/kg wet weight of oysters) in the Spanish Rio Tinto estuary, and the higher environmental mercury levels along the southern Tuscany coast and in the northern part of the Gulf of Trieste (sediments up to 47 ppm mercury dry weight) serve as examples of increased levels due to mobilization of trace metals by mining activities. The natural mercury concentrations in certain Mediterranean fish such as large tuna and striped mullet (e.g., 6 ppm wet weight), is probably the result of a combination of two factors: long biological half-time and the age of the fish. High levels, particularly in marine mammals, have also been observed in other areas.

Many industries release trace metals into the environment, which can reach the sea through a variety of routes. Generally, trace metals are discharged together with other wastes such as sewage, detergents and other inorganics. Interaction with these other wastes and the various components of the sea-water alters the original physico-chemical forms of the trace metals. In most cases it is difficult to determine the individual physico-chemical forms separately, but these forms largely determine the fate of the metal in the environment. For example, particulate forms

are more readily accumulated by filter-feeding organisms and are taken out of the water column more quickly. Trace metals complexed by detergents and other organics contained in sewage are much less absorbed than metals in ionic form. On the other hand, metal alkyls such as methyl and ethyl mercury are more extensively absorbed by biota than inorganic mercury.

Observations in the field are important for an adequate understanding of the distribution of trace metals after waste release. Thus, in one English estuary, (the Severn), it has been shown that the levels of cadmium and copper in invertebrates such as limpets and shrimps were correlated with concentrations in the environment, increasing towards the contamination sources. Similar increases towards a source have been reported for an Italian chloralkali plant, where although about 25 kg of mercury per day were released before 1974, the concentrations in sea-water, sediments and biota returned to background levels at about 10 km from the release point. Obviously, the trace metal concerned and the amounts discharged, together with the natural transport conditions in the area (see chapter II), will largely determine the extent of the influence, but it is worth noting that such a large discharge had only a very limited impact on the mercury levels in the environment.

Ecosystem effects: The mere presence of trace metals does not indicate a potential to produce damage. Several (Fe, Cu, Zn, Co, Mn, Cr, Mo, V, Se, Ni and Sn) are known to be essential nutrients. An insufficient supply of an essential element will cause deficiency disease. Whether a metal is essential or not, exposure above a certain level may cause adverse effects. For some essential elements the body has a wide tolerance, whereas for others the safety margin between adequate supply and toxic exposure is relatively narrow.

Effects of metals on marine organisms are difficult to detect in the field because these contaminants are seldom discharged without other wastes, and any deterioration near a discharge site cannot usually therefore be attributed solely to excessive metal inputs. More data on the effects of substantial concentrations in conjunction with other wastes are needed, and correlating effects with residues in biota would help in the interpretation of results. However, it is clear that many benthic invertebrates can withstand high environmental levels of some metals, as shown by studies in metalliferous areas where run-off is contaminated.

Any attempt to assess the effects of metals on marine organisms must include controlled experimental studies. One approach is to use bioassays carried out under laboratory conditions and in the environment to predict toxic effects. For example, ionic copper is more toxic than copper complexed by a detergent, but organic mercury is more toxic than inorganic mercury. For many trace metals the juvenile stages of marine organisms are more sensitive by one to two orders of magnitude than the adults, and often phytoplankton and invertebrates (e.g., shellfish) are more affected than fish. Some trace metals will reach higher body levels when offered through the food-chain than when present only in the surrounding water. The presence of one metal can reduce the toxicity of another (antagonistic effects), as has been shown in some cases for selenium and mercury. Although bioassays allow us to examine many factors and parameters of toxicity, their use in predicting toxic effects under environmental conditions is limited because tests are often carried out with the ionic form of the metal and without considering the exposure through food organisms, and also because exposure time is limited and often does not exceed four days, so that only short-term lethal effects at unrealistically high concentrations are examined.

A second approach is to extrapolate from detailed laboratory studies in which organisms are exposed to sublethal concentrations of metals. Many results from such studies are available and some of these suggest that sub-lethal effects may be

expected on the morphology, physiology or behaviour of marine organisms at concentrations not many times higher than those found in contaminated sea areas. It is usually difficult to extrapolate these results to the sea with confidence, since the conditions of the experiment are bound to be artificial. A step towards more realistic experimentation has been made recently by the use of enclosed ecosystems, e.g. floating bags in the sea or underwater benthic chambers. Data from such experiments tend to confirm that relatively low concentrations, sometimes within an order of magnitude of the background level, could have sublethal effects on organisms and be detrimental to their survival. Further work is required to evaluate these results in terms of the sea, and the use of experiments on biochemical and physiological effects on organisms is relevant (GESAMP 1980b).

Human health effects: In Minamata Bay, Japan, methylmercury from a chemical plant was discharged to the bay for at least 30 years up to 1968. Severe mercury intoxication affected human consumers of fish and there were a number of deaths. After the Minamata incident, particular attention has been paid to the concentrations of some metals in edible fish and shellfish. Extensive surveys have been made, particularly in the North Atlantic, and intercalibration exercises have been carried out to ensure that the collection and analytical methods permit comparison of data from different laboratories. Interpretation of data is not always straightforward because of high natural variation, but this is reduced by careful selection of the age, sex and condition of the specimens analysed. Results of such surveys do not suggest that there is any general threat to average human consumers from metals in the sea. A threat can be evaluated by calculating the number of meals which would be required to exceed an upper intake level based on environmental criteria elaborated by FAO and WHO for each metal, the provisional tolerable weekly intake (PTWI). If the number of meals required is high in relation to the consumption rate, then the chances of exceeding the PTWI are low.

Only for mercury and only for certain groups of consumers who eat larger than normal amounts of fish is there a significant risk. However, epidemiological studies among fishermen and their families have shown that, although mercury levels in their blood and hair are much higher than average, intoxication from mercury could not be diagnosed. Further research is required to assess these data. There is clearly at present no general public health risk.

Discussion: Natural and human inputs of trace metals to the sea are reflected in elevated concentrations at least in the immediate vicinity of the source. The increased concentrations are usually less evident in sea-water than in sediments and biota. Examples of damage to ecosystems by metals are rare, and some organisms seem able to adapt to high environmental levels, such as those found in mining areas. High levels in industrial zones are usually associated with so many other contaminants that it is not possible to attribute any adverse effects to metals alone. From the public health viewpoint, surveys of edible tissue do not suggest cause for general alarm, but elevated levels in critical populations need attention.

IV.6 Radionuclides

Exposure to radiation is not a new phenomenon. Over geological time the ocean ecosystem has been exposed to low-level radiation from natural radioactivity present in sea-water, in sediments and in biota. The types of radiation, their energies, and their physical half-lives span a similar range to those of the artificial radionuclides. In the aquatic environment, estimated dose rates from the natural background range up to approximately 0.4 uGy (40 /u rad) per hour.

The major source of artificial radionuclides in the oceans, including those from fission, nuclear activation and fusion, has come from the uncontrolled

introductions resulting from the testing of nuclear weapons. This has produced low-level concentrations of radionuclides throughout the world's oceans. Global fall-out from this source is now declining and the resulting dose rates to aquatic organisms are calculated to be in the same range as those due to natural background radiation.

In more recent years the nuclear fuel cycle for power production has become a significant source and will continue to merit greater attention in the absence of further large-scale weapon testing in the atmosphere or under water. Release of radioactivity from fuel reprocessing plants is a major source in this cycle and the materials released are more restricted in their geographical distribution and therefore exist at relatively higher concentrations in the immediate area of a discharge. In the case of the longer-lived radionuclides, as a result of transport processes, lower concentrations may exist over large geographical areas. In general it would seem that, except for accidents or other abnormal operating conditions, the dose rates to aquatic organisms in the vicinity of waste discharges will not significantly exceed the natural background rates. Where higher values have been recorded, the maximum is in the region of 0.25 Gy (25 rad) per hour and this is unlikely to be exceeded.

By comparison with the contributions from weapon fall-out and reprocessing plants, the contribution from controlled disposal of low-level solid wastes and radioactive wastes from nuclear power plants has so far been relatively small. Nuclear accidents of various kinds have resulted in radionuclides entering the oceans but have made only small contributions to the total artificial radionuclide inventory.

Controlled disposal of low-level liquid wastes is strictly supervised by national authorities. In the case of low-level solid wastes, a rate of dumping, which should not be exceeded, has been defined by the International Atomic Energy Agency (IAEA) for the London Dumping Convention. In both cases the guidelines and recommendations of the International Commission on Radiological Protection (ICRP) are taken into account. These recommendations refer to the limitation of human radiation exposure since it has been established that this consideration will place the most restrictive limits on the introduction of artificial radioactivity to the environment.

The potential exposure of marine biota and man depends on a number of factors. The radiotoxicities of the artificial radionuclides vary widely and their significance in a particular environment depends on the quantities released, the transport and distribution of the individual radionuclides after release, reconcentration in the environment, and the uses made of the environment which may lead to radiation exposure of man (see chapter II).

Ecosystem effects: Ionizing radiation can have a direct impact on organisms themselves (somatic effects) or, by irradiation of the germ cells, can affect the progeny (genetic effects). There is a large body of literature on the effects of ionizing radiation (IAEA 1976) on aquatic organisms, but much of this research is on the effects of acute doses of radiation. Acute lethal radiation doses for various groups range from 1-10 KGy (100-1,000 krad) for bacteria, algae and protozoans to 0.01-1.0 KGy (1.0 to 100 krad) for molluscs, crustaceans and fish. Experimental evidence is limited, but the most sensitive aquatic organisms appear to be teleost fish, particularly the developing eggs and young of some species. Some mortality has been observed at acute doses of 1 Gy (100 rad). Under experimental conditions of chronic exposure, a dose rate of 0.02 Gy (2.0 rad) per hour produced complete sterility in one species of fish after four months, and some effects on physiology or metabolism are recorded at dose rates of about 0.01 Gy (1 rad) per hour. There

is some experimental evidence that one result of irradiation stress at low levels could be increased fecundity. Extrapolation of these laboratory-derived effects to those that could occur at dose rates currently possible in the environment has proved difficult even in the most contaminated areas, e.g. Bikini atoll in the Pacific and at the discharge areas at the Windscale fuel processing plant in the N E Irish Sea. Assessment is further complicated because, even at the levels found at these sites, it is difficult to distinguish between the extrapolated effects of radiation and changes in population density due to natural environmental parameters. A further complication is that with chronic exposure at low rates, there will be an opportunity for the repair of damaged tissue, and at some rates the damage and repair may balance so that no progressive effect would be observed.

A consideration of genetic effects is beset with some of the same difficulties - lack of experimental data that can be extrapolated realistically, and absence of effects data from field observations. The concern here is that an increased mutation rate, resulting from exposure to chronic low-level radiation (or some other carcinogen for that matter), could affect the fitness of a population. However, it should be noted that, in general, aquatic populations have high reproductive rates on which selective pressures are strong and the value of a few or even thousands of individual organisms is insignificant as far as the long-term well-being and structure of the population is concerned. Thus, in aquatic populations where, for example, less than 1 per cent of the fertilized eggs are normally expected to mature to reproduction (i.e. to comprise the effective gene pool), and with the conservative assumption that all radiation-induced mutations are harmful to the population, it has been predicted that no significant deleterious effects are likely to be produced at the low dose rates in existing contaminated environments (IAEA 1976).

Human health effects: The assessment of public health risk from radioactivity has probably received more attention than any other type of contamination, and the critical pathway approach has been most widely used (see chapter VII). The objective of this approach is to determine the permissible discharges rate for each radionuclide. Site-specific hydrographic data allow the equilibrium concentrations in the receiving water mass to be estimated for unit rates of introduction. These are combined with the appropriate accumulation factors to determine the probable concentrations of radionuclides in those compartments of the environment identified as being likely to engender the greatest degree of human exposure. Information on the consumption rates of contaminated seafoods or occupancy times of contaminated beaches is then used to calculate the daily intakes of the radionuclides or the daily radiation exposure. These radionuclide concentrations in organisms, sediment and water are then translated into radiation exposure rates based on habitat or consumption rates, either directly in the case of external exposure, or indirectly in the case of internal exposure, and compared with ICRP-recommended dose limits. This then sets limiting rates of release for individual radionuclides.

To ensure that no member of the general public receives exposure in excess of the ICRP dose limit it is necessary to identify individuals or groups of individuals with exceptional habits which would lead to the highest potential degree of exposure (critical groups).

When post-operational programmes of environmental monitoring are carried out at disposal sites, there are two objectives. The first is to provide data to confirm that the exposure via the critical pathways does not exceed the dose limits and to develop appropriate estimates of collective dose to large population groups. This is normally achieved by periodic sampling and radioanalysis of environmental materials, including those that are directly responsible for exposure (the critical materials) and by a comparison of these results with those used to calculate the derived working limits.

The second objective is to validate the original model on which the assessment is based. These programmes will, where necessary, also provide the base data to validate the predicted exposure of organisms. The major concern in relation to deep-ocean dumping of solid radioactive waste is whether we have adequate data to compute the distribution of radionuclides on short to intermediate time scales, particularly when we are dealing with longer-lived radionuclides.

Recently published data on human radiation exposure as a result of the Windscale discharges to the Irish Sea are relevant. The limiting radiological situation is posed by the critical pathway involving the consumption of marine food and shellfish contaminated by the radionuclides of caesium. The individuals comprising the critical group in this pathway received during 1978 26 per cent of the dose limit. (The collective dose in this pathway for the UK population as a whole was 113 man-Sv. in 1978, whereas the collective dose to the population of Western European countries - 1.4×10^8 persons - was somewhat lower). These figures represent exposure resulting from the largest controlled discharge of liquid radioactive materials directly to the marine environment, and doses from all other direct disposals are small fractions of these figures; for example, doses to individuals resulting from deep-sea disposal of solid waste into the North-East Atlantic are less than 0.1 per cent of the ICRP dose limits.

Discussion: As long as the disposal of low-level liquid and solid radioactive wastes to the oceans is conducted within the international radiation protection recommendations of ICRP and the guidelines of IAEA and the London Dumping Convention, no public health problem should arise. With regard to marine organisms, the estimated dose rates, even in those environments most contaminated by radioactive waste, are not expected, based on extrapolations from laboratory research, to result in significant somatic or genetic effects.

IV.7 General discussion

The foregoing sections consider the effects of five groups of contaminants. In certain situations, for example immediately under an oil slick or at the centre of a sewage sludge dumping ground, any one of these groups may be the dominant agent of pollution, but frequently the problems arise from the combined effects of mixtures of the various groups. The combination of different types at the disposal stage is a feature of some industrial wastes. These combined wastes may include solid matter, containerized material or liquids, any of which may be relatively inert or highly toxic. The method of disposal will to some extent depend on the material, but may be via an outfall, by dumping, or in some cases by incineration from ships at sea. The careful selection of disposal sites is important and this is the subject of an earlier GESAMP report which is at present being updated (see chapter II).

Mixing of contaminants also occurs after input to the sea and this is perhaps one of the major problems of marine pollution. Deterioration of environmental quality can arise from the mingling of many inputs from different sources. Areas particularly susceptible are industrialized estuaries and coastal regions such as the well-documented New York Bight where plumes from different disposal operations can overlap (Gross 1976). The effects may be subtle - slight reductions in growth or other physiological or biochemical processes, or they may be manifest at the population level in terms of changes of the species structure of ecosystems. Such effects, whether subtle or obvious, are often difficult to link directly to specific contaminants, even to attribute unequivocally to pollution, without careful study.

One approach to assessing pollution effects which is receiving increasing attention is the study of fish and invertebrate pathology as an indicator and a

measure of environmental degradation. Diseases and abnormalities, including chromosomal damage in eggs, ultrastructure changes in gill epithelium, tumours, infectious diseases and skeletal anomalies may all to some extent be connected with polluted habitats. Apart from using pathology in this way as an indicator, its possible adverse effect on natural resources should be recognized. Pollution effects may also be detected by applying a wide range of experimental approaches and field observations involving studies of biochemistry, physiology, morphology, behaviour and genetics (ICES 1980a). This could lead to a better understanding of the long-term effects and of their general ecological implications (GESAMP 1980b). These matters are further discussed in later chapters.

CHAPTER V

USES OF THE MARINE ENVIRONMENT
IN RELATION TO POLLUTION

V.1 Introduction

Uses of the marine environment by man include exploitation of living and non-living resources, recreation, transport, waste disposal and coastal development for various purposes. Some of these operations are affected by contamination while others cause it; some can co-exist without interference, while others are mutually incompatible. In this chapter, the uses of the marine environment are briefly reviewed and their susceptibilities and interactions discussed.

V.2 Exploitation of living resources

Fisheries, in the broadest sense, may be taken to cover the exploitation by man of any form of marine life, including not only pelagic and demersal finfish and shellfish, but also a wide range of other plants and animals - seaweeds, invertebrates and marine mammals. Exploitation refers to the hunting of wild stocks and the controlled operations of mariculture.

The latest Food and Agriculture Organization of the United Nations (FAO) Review of the State of the World Fisheries (FAO 1981a) based on catch statistics for 1978 and 1979 shows an annual increase of about 1 million tonnes in reported landings, giving an average growth of about 1-2 per cent per year. This fits the annual average catch increase recorded since 1968, which is much slower than the average growth of 6-7 per cent per year during the previous two decades. Examples of catches, extracted from the FAO Yearbook (FAO, 1981b) are presented in tables V.1 and V.2. Table V.2 demonstrates the small increasing trend in catches in most areas. The Peruvian fisheries are a noticeable exception to this, and the dramatic change in these catches is most likely due to natural variability in the stocks as well as to overfishing, demonstrating the large yield an upwelling area can give and the vulnerability of such an area to natural fluctuations.

According to the FAO report (FAO 1981a), increases in the catch rates are diminishing because "there are now few unexploited stocks of abundant species which can readily be caught and marketed by conventional methods, and which provided the opportunities for rapid expansion in the 1950s and 1960s". Prospects for future growth therefore primarily depend upon the potential in the oceans to produce more fish, a potential which must be related to the conditions in the marine ecosystem.

Figures for the potential yield should, however, be used with great caution since a number of factors will influence the realization of this potential. Taking these factors together, FAO (1981a) concludes that the rate of growth of world catch during the next few years will remain small. This, however, does not imply that growth of the benefits received from fisheries will also remain small. Greatly increased benefits could come from improved management of the fisheries, from rebuilding depleted stocks, reducing economic loss through excessive fishing effort, and from better distribution of fishing between different interests.

Table V.1 : World nominal catches of fish in thousands of metric tons; examples from various areas (from FAO 1981b)

Division/area	1975	1976	1977	1978	1979
World total	66 487	69 870	69 170	70 548	71 287
Marine areas	59 294	62 757	61 806	63 421	63 807
Atlantic, North-East	12 015	13 163	12 576	11 675	11 708
Mediterranean and Black Sea	1 294	1 311	1 145	1 231	1 316
Atlantic, Antarctic	39	40	265	293	452
Pacific, North-West	17 254	17 558	18 198	18.440	18 317
Pacific, South-East	4 381	5 780	3 937	5 474	6 899

Table V.2 : Nominal catches of fish, examples by countries (from FAO 1981b) in thousands of metric tons

Country	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Japan	8 825	9 360	9 709	10 092	10 101	9 895	9 994	10 123	10 184	9 966
China	3 096	3 358	3 680	3 793	4 134	4 247	4 320	4 463	4 394	4 054
Peru	12 535	10 529	4 725	2 329	4 145	3 448	4 344	2 537	3 369	3 682
India	1 756	1 852	1 637	1 958	2 255	2 266	2 174	2 312	2 306	2 343
World total catches				62 824	66 597	66 487	69 870	69 170	70 548	71 287

Great concern has been expressed on the situation arising from over-exploitation of marine mammals, in particular whales, and especially in areas where there has appeared to be a risk of extinction. FAO (1981a) considers that the marine mammals most threatened are the three species of monk seal, the Caribbean monk seal being probably already extinct and the Mediterranean and Hawaiian species being scarce and declining. It has already been noted (chapter IV) that in some areas (e.g. the Baltic and the Dutch Waddensea) adverse effects on marine mammals have been linked to pollution by organochlorines. Some other seal stocks have been increasing since catching was stopped or controlled. For instance, the harp seal stock in the north-west Atlantic now shows an increased abundance following the introduction of quotas in 1972.

Finally, the rising importance of aquaculture is evident. This includes a range of activities from hatchery-based restocking and sea ranching projects to various forms of intensive culture. Animals such as oysters, mussels and mullet which are part of short food-chains are particularly economic. Marine aquaculture at present amounts to about 5 million tonnes annually, but could double in the next decade. Among its attractive features are better management opportunities compared with the increasingly overfished wild stocks, and the better national control that can be exercised in coastal waters.

Effects of pollution

The effect of pollution on fisheries may range from the immediate, such as the sudden death of a substantial number of fish, to the more prolonged e.g., defective development or reproduction. Effects may be directly on individual fish (eggs, larvae, or adults) or indirectly, through the food. In attempting to assess the impact of environmental deterioration on fisheries, it is useful to separate the consideration of effects of single spills or incidents on the one hand from the possibly longer-term effects of continuous discharges or diffuse inputs on the other. In the paragraphs below these subjects are briefly discussed; however, a number of other operations can have impacts on fisheries. Dredging for sand and gravel, for example, can pose a serious threat to those species that depend on beds of these sediments as spawning or nursery grounds; the activity of the dredgers alone can interfere with fishing, through the presence of the vessel and through physical alterations to the fishing ground by its operation, resulting in difficulties in the use of demersal fishing gear. The problem of interference with fisheries is, of course, a more general one and is particularly acute in regions where oil exploitation is in progress. The presence of drilling rigs and production platforms on fishing banks and the laying of miles of pipeline on the sea floor all result in "no go" areas for fishing vessels and the operations in general tend to produce accumulation of debris on the sea floor. These effects, together with the increased shipping traffic, are all of immediate concern to fisheries (GESAMP 1977b).

Incidents

Probably the most common and certainly the most spectacular pollution incidents have been caused by oil - either by shipping accidents or by pipeline or wellhead malfunctions. As a result of increasing requirement for petroleum throughout the world, transport by sea and exploitation of resources under the sea have multiplied, and in recent years some incidents have been extensively studied so that the effects can be evaluated with some confidence. As discussed in chapter IV, effects on local sections of the ecosystem can be disastrous, but adult fish are mobile and can avoid high concentrations of oil. Eggs and larval stages can be exposed immediately under a slick to levels of oil that have been shown experimentally to be lethal, and indeed high mortalities have been recorded under fresh slicks, but these are local

and transient effects and there is no documented case of a total fishery being destroyed or even of a whole year-class being eliminated by an oil spill. While the definitive assessments of long-term effects of the AMOCO CADIZ incident and the IXTOC-1 blow-out are awaited, experience to date suggests that, in general, oil does not pose a long-term threat to fisheries.

Dumping

The effects of dumping on fisheries can also be assessed, often with some confidence in those situations where the dumping ground is isolated from other inputs and the composition and amount of material dumped are accurately known. Since dumping grounds should be selected with the intention of limiting adverse environmental effects, and since the method of disposal should be arranged also to further this aim, it is not unexpected that in many cases correct choices are made and the effects are acceptable (see chapter II and GESAMP 1975). It is only when the dumped material accumulates that a measurable deterioration of the environment may occur. For example, in some sewage sludge disposal sites slow alterations are caused to the sediment, making the ground uninhabitable by commercial shellfish that were previously present. Also, the benthos may be changed to a community which is less acceptable as food for fish. Other types of dumped material can have comparable effects. Thus, the dumping of dredged spoils may result in both smothering and toxic effects, while even the most chemically inert material can blanket the ground, bury fauna and change the character of the sediments.

However, even where an effect can be clearly demonstrated on an isolated dumping ground, this effect will usually be restricted by the nature of the dumping operation to a relatively small area, so that only a small part of the commercial fish stock will be exposed to contamination. The most serious situations are those where several dumping grounds are close together, so that the pollution sources may then coalesce spreading the impact over a wider area.

Outfalls

Outfalls as distinct from dumping operations, will, for the most part, be of concern only in inshore areas. Land-based pipelines discharging into the sea can be located at sites most likely to aid dispersal; they should be fitted with adequate diffusers and the discharge can often be arranged to suit the best tidal conditions to achieve optimal dilution and dispersion. In view of this, it is possible to confine any adverse effects on fisheries to the immediate vicinity of the discharge. Offshore discharges, as for example from oil drilling rigs and production platforms, are usually controlled. Enhanced concentrations of contaminants are unlikely except close to the source, so that again any effect will be local and confined to organisms which are sensitive and react rapidly or which are unable to move away.

Diffuse inputs

These may be general inputs to the sea from land run-off and rivers, or from the atmosphere. Recent measurements have shown that in some cases the atmospheric route can account for a significant proportion of certain contaminants (see chapter II), particularly organochlorines and some metals, but because of the diffuse nature of the inputs, effects on biota are difficult to detect. Although atmospheric input is likely to be relatively more significant in open-ocean situations, there is no indication that it has threatened the ecosystem or put oceanic fisheries at risk. Enhanced levels of some contaminants have indeed been recorded for a few oceanic species, but (as discussed below under 'Tainting') follow-up studies of, for example, mercury in swordfish, tuna and halibut have suggested this is natural.

Contaminants present in land run-off and river inputs are even more difficult

to assess. They arise from a large number of diverse sources and are not directly controllable. Along coasts exposed to the open sea, rapid dilution and dispersion are likely, so that high concentrations of contaminants would not be expected in the water. The situation may be different in more enclosed areas where land and river run-off mingle with a variety of discharges, and in industrialized situations the maximum opportunity occurs for a build-up of contaminants. In fact, estuaries, lagoons and bays are usually the areas where significant decline of environmental quality is recorded and where reductions in fisheries have been documented (see also chapters II and VI). Nevertheless, even though there is circumstantial evidence linking increased contamination with reduced fisheries, it is usually difficult to demonstrate an unequivocal quantitative relationship and further study of such situations is required. Perhaps the best confirmation that general contamination of estuaries has had an adverse impact on fisheries comes from those locations where a progressive clean-up has taken place over a period of years and an associated improvement in fisheries has been recorded.

Plankton blooms

Apart from the normal cycle of plankton growth and decay, short-term blooms, usually of single species of phytoplankton, may occur in areas unaffected by contamination. These must be recognized as natural perturbations in the ecosystem, and although their cause has not been established, it seems reasonable to suggest that they occur when a particular combination of physical and chemical circumstances provide conditions to trigger the bloom and to allow it to develop. However, in recent years, there has been increasing documentation of phytoplankton blooms that may be connected with contamination and might therefore be controllable if the conditions that generated them were well enough understood.

The blooms vary greatly in character, and may be toxic or non-toxic. Several genera and species of marine algae can give rise to toxic blooms, and several specific toxins have been identified. Some of these are lethal to marine organisms, whereas others are simply accumulated by them but can cause distress or death to the human consumer of affected fish or shellfish. Such blooms have been recorded from many parts of the world, and indeed in some places they occur regularly, following a seasonal pattern which can be predicted for a given coastal area. In these situations, precautions can be taken to protect public health by surveillance of the shellfish species usually involved and by prohibiting sales of these species if they become affected. Unfortunately, however, prior warning is often impossible so that illness from this cause is not infrequent and death sometimes results.

Not all blooms are due to toxic organisms, and while the effects of non-toxic blooms are of less direct concern to public health, they can have a significant impact on the environment and sometimes on fisheries. This impact operates mainly through the bacterial decomposition of the large quantities of organic matter produced, which can impose an immense oxygen demand on the water column and on the bottom when the material is deposited. Anoxic conditions may thus be generated which can kill plankton, fish and bottom-living organisms in the affected area. The most spectacular recent event of this kind took place in 1976 off the east coast of the United States, where hundreds of square miles were affected and a massive mortality of commercial species was recorded (Swanson and Sindermann 1979).

Further effort could usefully be directed towards understanding the conditions which give rise to plankton blooms so that predictions can be made and appropriate control measures adopted.

Tainting

One type of effect that can be clearly recognized and can often be readily

quantified in cash terms is tainting of the edible tissues of commercial species, producing an unpleasant taste and colour change which can result in the affected produce being unmarketable. This can be caused by a variety of contaminants, but metals such as zinc and copper in shellfish and oil in fish and shellfish are probably the most common. Unfortunately, even a rumour that a particular stock is tainted can injure the reputation of a fishing area or a merchant so that sales are affected. As a result, the suspicion that a catch might be tainted could be enough to persuade a supplier to withhold his landings from the market. There is no doubt that the possibility of tainting can be the immediate impact of a large oil spill on fisheries and there is equally no doubt that significant financial losses can occur and have occurred in this way. However, the taint can be lost by depuration in clean water and again the effects tend to be restricted to a specific geographical location and not to affect a whole stock.

Public health threat

Contamination by micro-organisms derived from sewage give rise to a significant public health risk. This threat is most relevant to shellfish beds in shallow waters in the vicinity of sewage outfalls and the correct approach is to ensure that such outfalls are properly positioned, although it is usually possible to treat affected shellfish so that any human health threat can be eliminated. When sewage sludge is dumped offshore there is potentially a similar threat, but in most cases the rapid dispersion and die-off of micro-organisms foreign to the marine environment ensures that there is little risk.

Perhaps the most common form of residue is the accumulation of a contaminant which, although not detectable by taste, is measurable by chemical analysis and is considered to be potentially dangerous to human consumers. Examples of this are mercury in swordfish and tunas, and PCBs and organochlorine insecticide residues in some fish. This type of contamination is not derived from a single incident but can affect fish stocks on a long-term basis and over a wide area. However, it is increasingly suggested that the trace metals in oceanic situations often arise from natural contamination rather than pollution, and that the effect of such natural contamination on consumers may be negligible; however, neither of these arguments will apply to organochlorines.

Sub-lethal effects

Apart from direct mortality, there is the fear that contaminants in the sea may produce sub-lethal effects which would have an impact on commercial species. Experimental studies have shown that fish eggs and larvae exposed to certain metals do not develop normally and, if they survive, may produce adults with skeletal anomalies that must reduce the survival rate of the affected individuals. Field observations in polluted areas of the New York Bight suggest that developing stages of fish may be damaged, resulting in abnormal embryos. Finally, the relationship between diminished environmental quality and various forms of disease in fish and shellfish is of increasing concern, and a positive correlation has been suggested for at least some diseases. However, most of such effects are likely to concern individual organisms or, at most, limited portions of a stock, so that a significant threat to a whole fishery is unlikely. Nevertheless, the disappearance of fisheries from contaminated estuaries, which has already been referred to, cannot be ignored, and the possible risk of general sub-lethal effects requires further investigation.

Aquaculture

The increasing growth of marine aquaculture throughout the world demands that any assessment of pollution effects on fisheries should include a consideration of

this aspect. The extensive development of sea enclosures of various kinds makes marine fish farms highly vulnerable to pollution from many of the sources already discussed. Thus, an oil spill can result in direct mortalities or can taint the stock and impair facilities, while sewage discharges may produce a public health risk. Equally dangerous may be the development of plankton blooms which can damage the stock by oxygen reduction or by direct toxicity. Aquaculture itself may also give rise to nutrient releases if not properly managed. It should be noted that aquaculture may benefit from the results of other human uses of the environment such as heated effluents and artificial reefs.

V.3 Exploitation of non-living resources and other uses of the sea

Minerals

Offshore oil and gas production accounts for about 90 per cent of the value of mineral resources recovered from the sea bed. In 1973, about 18 and 10 per cent of the world petroleum and total gas production, respectively, were derived from the sea. By 1977 offshore petroleum production reached about 20 per cent of the total. Exploration is moving farther offshore and investments are increasing. It can be expected that offshore production will continue to increase considerably and will expand to new areas of the world oceans.

As an example of the rapid development that can occur, exploratory drilling for oil started in Scottish waters in 1967, and increased dramatically in 1970. Production began in 1975 with proven reserves of over 1,000 million tonnes, and was around 100 million tonnes per year in 1980.

Mineral resources in superficial deposits (i.e., unconsolidated sediments on the sea floor) include sand and gravel, tin, heavy mineral sands, metalliferous deep-sea muds, iron sands, diamonds, phosphorite nodules and manganese nodules. Current exploitation is limited mainly to depths of 30 to 50 m, and the material is recovered by dredging (GESAMP 1977b). Sand and gravel exploitation is particularly important and demands for offshore sources are increasing in certain areas (e.g., the North Sea, in Japan, and in the United States). Certain metals are being mined, tin in East Asian areas being an important example. Techniques for recovering deep-sea manganese nodules and metalliferous deep-sea muds on an industrial basis have been developed.

Effects of sand and gravel extraction are largely confined to the exploited sites and include alteration of bottom topography, wave conditions, water circulation and sediment transport, and increased turbidity. Coastal protection must be considered since, otherwise, beach changes and effects on coastal structures can be serious.

Minerals are also extracted from sea-water, the main items being salt, magnesium and bromine. Desalination plants are important for the water supply in many areas.

Energy

In recent years there has been considerable interest in obtaining energy from ocean waves, currents, tides, and temperature and salinity gradients. However, the only major breakthrough has been in the field of tidal energy. Potential consequences of development of large tidal power plants for the local coastal environment have been investigated, and ocean thermal energy conversion (OTEC) plants are being studied in research programmes and in experimental plants.

However, it is premature to give an assessment of implications for the marine environment of a large-scale deployment of such plants. A GESAMP Working Group is currently studying this problem.

GESAMP (1977b) presented a review of potential causes of pollution arising from exploration and exploitation of the sea bed. The presence of offshore structures, such as platforms, wellheads, and pipelines, will restrict fishing activities in the vicinity of the site and may also lead to local redistribution of fish resources. Fishermen claim that their operations are significantly affected by various items of debris discarded on the sea bed. Disposal of formation cuttings and losses of drilling muds may affect fish feeding in the area by giving rise to tainting, but there is no documentary evidence of this. Dumped drilling muds and cuttings affect marine organisms by altering the sediments, blanketing the bottom fauna, and introducing toxic materials. Effects that have so far been demonstrated are highly localized, and their time-scale in American waters is 10 to 20 years.

Other uses of the marine environment

Transportation and associated operations are major uses of the ocean, the revenue being considerably larger than that of the fishing industry and comparable to that of the offshore oil industry, of about $40 billion in 1975. In the period 1965-1975 the merchant fleet of the world nearly doubled in tonnage, oil tankers comprising a large part of the fleet (about 40 per cent in 1975). There is contamination of the sea by shipping. Much of the sometimes large volumes of beach litter, for example, is derived from this source, and profiles of chemical measurements across shipping routes indicate higher levels of some metals in the traffic lanes. It is calculated that a large vessel may contribute one ton of copper to the sea each year from the antifouling paint. Oil contamination from ships on passage has already been discussed. Ships may also transfer biological species which in their new environment may pose a threat to the indigenous species.

In recognizing problems related to the pollution of certain sea areas by discharges of ballast waters and tank washings from chemical tankers, detailed requirements for the control of these discharges have been developed. For this purpose the evaluation of the environmental hazards of harmful substances carried by ships has been a task of GESAMP since 1972. Due to the increasing number of chemicals transported at sea, GESAMP agreed to undertake the ongoing task of evaluating the environmental hazards of additional substances carried by ships, and a comprehensive report containing hazard profiles of more than one thousand substances is being prepared. Discharge of sewage and disposal of garbage from ships are strictly controlled.

Port developments have been necessary for receiving large special carriers, and there have been two trends. To avoid traffic congestion at established ports, offshore terminals and artificial islands have been developed to receive, for example, very large crude carrier tankers. Few established ports can receive these large tankers. Specialized ports have also been developed as part of transportation networks, and used, for example, to re-distribute cargo to smaller units. It is evident that the increased transportation has required such development, but it is also evident that this places considerable strain on the local environment. Careful planning in the construction phase, including site evaluation, is necessary, and the conditions of the marine environment in the region must be assessed and taken into account, as also must the effects of port dredging for navigational and other purposes. The possibility of changes in the coastal erosion pattern as a consequence of coastal contructions must be considered. It may be expected that the construction of artificial islands will increase, not only as port facilities but also for processing plants; e.g., in manganese-nodule mining. Reliable examples of

impacts of such structures on the environment cannot as yet be given. Development of harbours however implies several sources of pollution, from land, from ships and in dredging operations. Recent studies of trace metal contamination in the mussel, Mytilus edulis, suggest that a number of trace elements (e.g., copper) are introduced to the coastal zone as a result of ship activities and that harbour-related activities can be an important source of contamination, comparable to wastewater discharges.

Cooling water

Industrial developments along the coast include power plants, gas and chemical plants, refineries and pulp mills, all of which use sea-water for cooling purposes. Although all these can contaminate heavily on a local basis, it is clear that they will continue to be developed at the coast. Careful planning, management and control are therefore needed, including appropriate effluent treatment for liquid and gaseous emissions. Particular attention should be paid to non-degradable chemicals that may accumulate in sediments and biota.

Effects of cooling waters from power plants have been demonstrated locally and include increased toxicity of chlorine and chloramine due to the elevated temperature, the effect of the heat itself and the potential effect of closing down the heat supply. In the tropics the temperature effect alone may be important. Also the intake has been shown to have damaging effects on fish larvae and zooplankton. Thus there are several factors which can give rise to local disturbances by cooling water systems for power plants, but it is still considered to be a local problem. A significant effect may be that pollution, including heat, can prevent migrating species such as salmon reaching their spawning grounds.

Recreation

Recreation is another major use of the marine environment and many conflicts can arise between this and industrial uses.

Several examples of coastal area development including their potential impacts on the coastal zone are discussed by GESAMP (1980a). In that report basic programmes for obtaining part of the information required for proper planning are also given, as well as a strategy for assessing the environmental effects of coastal area development.

Waste

Finally, it is recognized that man has for long used the sea for disposal of much of his wastes, and indeed a major part of this report deals with an assessment of the impact of that usage. The ocean has a substantial (but not infinite) capacity to dilute, disperse and degrade waste material, but it is clear that an accurate record of input is required and that regular surveillance of environmental levels of contamination is necessary. Given these conditions, and that they can be coupled with experimental and field information linking doses and residues with responses of organisms, it should be possible to construct an accurate picture of the impact and to reach a decision as to whether the disposal is acceptable. Since we are dealing in this context with point sources of input, the criteria for acceptability of effects will vary greatly from case to case. They will be related to local environmental conditions, to other uses of the area, and to its resources. Possible interaction between natural variability in time of the consumption and the frequency of disposal should also be taken into account. Taking into consideration the outline above, the use of the sea for waste disposal should be acceptable, provided that such introductions are carefully regulated and controlled and take into account the concepts outlined in chapter VII.

V.4 Discussion

From this brief review it can be concluded that man's use of the marine environment could both threaten and be threatened by deterioration of the health of the oceans. While there are extreme opinions at both ends of the spectrum on how this should be assessed, the current consensus is that contamination can kill individual organisms and adversely affect others at the sublethal level, but so far whole fish stocks do not seem to be significantly affected. However, impact may be especially adverse on parts of a stock or on particular geographical areas. A major part of the sea's living resources depends directly or indirectly on coastal zones, so that diminished water quality, destruction of habitats and interference with food-chains can imply serious threats to these resources which, if integrated over a large number of sites, could become significant on a global scale. Point source inputs to the sea, from discharges or dumping, can be controlled, and an increasing number of national and international regulatory bodies are now in operation with the aim of protecting the marine environment and ensuring coexistence of its varied uses. On the other hand, atmospheric inputs and substances in land and river run-off are largely unattributable to a specific source, and since they are a matter of more than just marine concern, their control requires a more widespread demand for good environmental practice. Finally, although natural inputs of contaminants cannot be controlled, they can be documented and their effects determined, so that a realistic assessment of the problems may be made.

CHAPTER VI

SPECIFIC PROBLEMS OF REGIONAL SIGNIFICANCE

VI.1 Introduction

Regional studies which are necessary for the management of inshore waters can contribute information on the state of the health of the oceans. The importance of co-ordinating such studies to provide reliable data on pollution in these areas must be emphasized. Co-ordinated programmes ensure that essential region-wide data are acquired to assess marine pollution and that participating laboratories will intercalibrate their analytical and sampling procedures so that data from different parts of a region are comparable.

Although studies are completed, under way or planned in many regions of the world, the Group did not consider it either practicable or necessary to examine each of these regions. Instead, a selection was made using three criteria: (1) Some marine pollution studies, which could serve as models for use in an assessment, should have been conducted; (2) the selected regions should represent a wide spectrum of natural conditions; and (3) taken together the selected regions should provide a wide geographical coverage.

Some of the selected areas have been much more intensively studied than others, one explanation being the available mechanisms for co-ordination as exercised by such bodies as the International Council for the Exploration of the Sea (ICES), by the Regional Seas Programme Activity Centre (RS/PAC) of the United Nations Environment Programme (UNEP), and by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The quality of data varies from region to region according to the analytical expertise available and to the degree of intercalibration of analyses by participating laboratories. For this reason, it is not possible at present to treat the oceans uniformly in the presentation of data on distributions of contaminants and their effects on the marine environment.

It should be noted that there are some excellent sources of data from certain international scientific investigations providing a reliable reference on concentrations of particular contaminants in oceanic areas. No separate open-ocean region has, however, been specifically dealt with here.

VI.2 Methodology in regional studies

Marine pollution studies conducted in the North Atlantic and the North and Baltic Seas have been co-ordinated by the International Council for the Exploration of the Sea (ICES 1977b; 1977c). Baseline studies were conducted and involved all the countries bordering these marginal seas. Guidelines derived from these studies and applicable to other areas were outlined in the Comprehensive Plan for the Global Investigation of Pollution in the Marine Environment (GIPME) (IOC 1976).

Intercalibration of analytical techniques is a vital component of such regional exercises so that the results of participating laboratories can be compared with confidence. It is, for example, only very recently and after several intercalibration exercises that data from the majority of ICES-participating laboratories is reaching an acceptable standard. Even now improvements are necessary for certain contaminants. It is also a fact that at low concentrations many laboratories still experience difficulties in achieving a desirable level of competence.

Based on experience gained it is apparent that to obtain data of adequate quality on contaminant concentrations in the marine environment is an expensive operation calling for highly trained personnel and in some cases expensive equipment. It is essential therefore, that before these resources are deployed on a programme of sampling and measurement, the objectives of the programme be clearly defined, since the continuous collection of data without a clear definition of purpose is unlikely to be a useful exercise. Experience in the North Atlantic and elsewhere has shown it is necessary to design sampling strategies differently to ensure that objectives such as trend assessment, compliance with health standards and pollution controls, or the illustration of geographical distributions, are met with the minimum of effort and the maximum degree of certainty.

For the evaluation of the mass balance of contaminants in any area, it is important to have reliable estimates of their input from various sources through different routes.

A review of the regional contributions on marine pollution shows that there are few areas where a concentrated effort has been made to follow all the essential procedures for conducting high-quality baseline studies. Even in the developed countries where the analytical capability is available, the co-ordinating mechanism to harmonize different coastal studies to provide a broad picture of conditions in the region is present only for some areas, such as those covered by ICES, UNEP's Co-ordinated Mediterranean Pollution Monitoring and Research Programme (MEDPOL) and the coastal areas of the United States. For some regions this is perhaps one of the major deficiences; the other deficiency is the lack of detailed information on transfer processes for contaminants as they leave the source and move through different media and across different interfaces, as discussed in chapter II.

VI.3 Selected geographical areas

This section contains a brief résumé of some marine regions that have been considered by the Group. The reader is referred to the original contributions on each region which are published in the Technical Supplement (IOC, in prep.). It should be noted that particular attention is not paid to the different types of ecosystem present in these areas. However, it should be recognized that all ecosystems are more or less sensitive to pollution stress. For example, an ecosystem which is stressed by low salinity as in the Baltic Sea or by high temperature as in the tropics may be more sensitive to the effects of pollution.

The Baltic Sea

The Baltic is a semi-enclosed body of brackish water surrounded by eight moderately densely populated States of north-eastern Europe. It is separated from the North Sea by sills 7-8 m deep in the Oresund between Sweden and Denmark and 17-18 m deep in the Belt Sea at Darsser.

Typically an area where run-off and precipitation together exceed evaporation, the annual river inflow amounts to 440-480 km^3 or about 2 per cent of the volume of the Baltic Sea. The precipitation balances the evaporation on an annual basis. The exchange between the Baltic and the open ocean is driven by river run-off and meteorological conditions, with a seaward surface outflow through the Oresund and the Belt Sea, and a subsurface inflow over the sills. The average residence time for the water in the Baltic has been estimated at about 35 years.

There have been long-term oceanographic changes in the Baltic that, coupled with inputs by man, have led to an oxygen decrease in the bottom water since 1900. The area of bottom water containing measurable amounts of hydrogen sulphide is estimated to have increased from zero in 1929 to 26×10^3 in 1959 and 84×10^3 km^2 in 1975, the latter value being the maximum so far. During 1969, the hydrogen sulphide zone extended into the Gulf of Finland. Although hydrogen sulphide was observed only in the eastern Gotland basin in 1976, the situation does not appear to be improving significantly.

The total input of organic matter, excluding primary and benthic production, has been estimated at about 5×10^6 tonnes of carbon per year, which compares with 26×10^6 t from primary production. Only about 10 per cent of the organic matter can be oxidized by the oxygen that is transferred to the Baltic deep water.

During aerobic conditions, the Baltic acts as a nutrient trap, inasmuch as both phosphate and nitrate are taken up by organisms and deposited in the sediments. During reducing conditions, the inorganic phosphorus is released from the sediments and added to the bottom water. Vertical mixing can transfer the phosphate to the euphotic zone, where it will help to increase primary production. The average primary productivity is about 100 g carbon per m^2 per year. Observations for the period 1961 to 1974 suggest that primary productivity is increasing.

Fish catch in the Baltic has been increasing since the 1930s owing primarily to increased fishing effort and improved techniques. In 1979 the total fish harvest was 800,000 t, mainly of herring, sprat and cod. Fish are affected by reduced oxygen levels, and cod generally avoid areas where concentrations are less than 2 ml per litre. Eel, salmon, flounder, sprat and plaice are also important Baltic species which may be affected by pollutants or unfavourable changes in water characteristics.

Pollution problems in the Baltic stem from sewage discharges from 17.5 million people living around its perimeter and from assorted industrial wastes, such as pulp and paper effluents. Annual input from domestic and industrial sources of phosphorus is about 7,500 t, and of nitrogen, 5×10^4 t. About 18,000 t of phosphorus and 50,000 t of nitrogen enter via rivers, annually. The annual input of organic material, given an equivalent biological oxygen demand, is estimated as 1.4×10^6 t.

Data on inputs to the Baltic indicate an annual mercury input of 30 t, with 24 t coming from domestic and industrial discharges and 6 t from rivers. Much of the mercury appears to be deposited in the sediments, leaving relatively low concentrations in the water (about 8 ng per litre). Most of the lead enters via the atmosphere (about 2,400 t, annually) and is largely removed from the water column by sedimentation. Annual atmospheric deposition of other metals was also estimated to be moderately high: zinc, 6,000 t; copper, 1,400 t; cadmium, 80 t; and mercury, 30 t. The total metal content of the Baltic has been estimated as: copper, 27×10^3 t; zinc, 68×10^3 t; and lead, 14×10^3 t. The metal content of fish is illustrated by the following values, given in ug per kg wet weight:

	Mercury	Cadmium	Copper	Zinc
Cod	20–880	2–50	0.03–2.4	1.2–9.2
Herring	40– 90	–	0.3–1.9	3.4–32.0

There have been several significant oil spills in the Baltic Sea, in some cases giving rise to considerable nuisance on beaches and in archipelagos. Long-term effects on benthos have been identified in localized areas, for example, after the TSESIS oil spill (Kineman et al. 1980).

Examples of organochlorine concentrations in mg per kg wet weight are:

	DDT and metabolites	PCBs
Cod	1 – 230	0.005 – 0.22
Herring	28 – 3300	0.02 – 2.0

Reproductive failure in Baltic seals has been associated with the presence of DDT and PCBs in these mammals. There has also been a significant negative correlation between reproductive success of the white-tailed eagle and the levels of DDT and PCB in their eggs. DDT and PCB levels in Baltic herring and salmon have been shown to be an order of magnitude higher than levels in similar species from the North Sea.

However, there have been declines in DDT, PCBs and mercury in biota of the Baltic during the last few years, following restrictions on the use and release of these substances. Lead levels in sediments have exhibited a dramatic increase during the last century and show no signs of diminishing.

Recently, an extensive co-operative assessment of the effects of pollution in the Baltic Sea has been carried out by the Helsinki Commission and ICES (Melvasalo et al. 1981).

In conclusion, large variations in the conditions, including long-term changes of nutrient and oxygen concentrations, have occurred in the Baltic Sea during the present century. These changes are partly natural, partly due to human interferences, and partly due to a combination of natural and human influences (see, for example, Melvasalo et al. 1981). The importance of considering fluxes in relation to environmental variability and deterioration, as discussed in chapters II and III, is well demonstrated in the case of the Baltic Sea. Varying river run-off, increasing input of organic material and nutrients from land, increasing inputs of substances from the atmosphere, releases of phosphorus from the bottom induced by chemical changes in the bottom waters, and changes in the fluxes between the open ocean and the Baltic have all contributed to the changing conditions. Adequate protection and management of the Baltic Sea as a natural resource requires a good understanding of the interactions and the variability of the fluxes as well as of the relationship between the variations and changing environmental conditions. The Baltic case also demonstrates the great importance of long-term series of observations and indeed the necessity of having data from such studies to explain environmental changes.

The North Sea

The North Sea essentially occupies the continental shelf of north-western Europe between the Scandinavian countries and the United Kingdom and is bordered by eight highly populated and industrialized countries. The area has rich biological resources, with annual production of 3 to 4 million tonnes, and valuable mineral resources, including sand and gravel, potash, coal, oil and gas. The North Sea is characterized by a high salinity of about $35^o/_{oo}$, relatively cool water, good exposure to the open Atlantic through a wide, moderately deep (100-200 m) channel, a substantial tidal range, which provides strong tidal currents and vigorous nearshore vertical mixing, and frequent strong winds which aid further in mixing the water. The volume of incoming sea-water from the north may be as high as 45,000 km^3 per year, while the English Channel - Strait of Dover inflow is probably less than 2,000 km^3 per year. Freshwater input from continental rivers is estimated at 120 km^3 per year, and from the United Kingdom rivers at 5 km^3 per year. Surface temperatures reach 14°-16^oC during summer. A thermocline at 6°-7^oC separates the bottom water from the upper layer in areas having a depth greater than 40 m.

Primary production offshore in the North Sea is estimated at 100 g carbon per m^2 per year. In the Southern Bight, between the south-east of the United Kingdom and the Low Countries, the impact of man is most evident in enhanced nutrient levels (e.g., 2 ug-at phosphate per litre) off the Dutch coast, compared with a winter offshore maximum of 0.3 ug-at per litre. The total supply of phosphorus to the Southern Bight from all rivers has been estimated at 70,000 t per year, compared to 40,000 t per year entering with Atlantic water through the Strait of Dover.

Pollution in the North Sea can arise from three main sources - industrialized, highly-populated coastal areas; oil industry activities ranging from drilling rigs and pipelines offshore to terminals and refineries onshore; and river inputs. Other significant sources of contaminants are from dumping of sewage sludge, dredge spoils and industrial wastes, and, for certain contaminants, input from the atmosphere.

The annual input of organic matter, expressed as biological oxygen demand, into the North Sea has been estimated at 546,000 t, being concentrated in coastal waters and unevenly distributed according to the location of outfalls and volumes of effluent discharged. It is also roughly estimated that the following amounts of other materials are released with the municipal wastewaters annually: organic pesticides, 1 t; PCBs, 7 t; zinc, 2.5×10^4 t; copper, 4×10^3 t; manganese, 6×10^4 t; and mercury, 22 t. Over 5 million t of sewage sludge are disposed of annually into the North Sea, most of which comes from London and is dumped outside the Thames estuary. Atmospheric input of metals into the North Sea has been estimated from rain-out measurements as (in tonnes per year): copper, 6; lead, 11; iron, 1100; and manganese, 130. Examples of concentrations of some metals in sea-water and organisms in the North Sea are as follows:

		Cadmium	Lead	Copper
Sea-water	ug/l	2.8-6.0	-	0.004-0.006
Cod	ug/kg wet wt.	20-50	0.1-0.3	1.1-2.6
Herring	ug/kg wet wt.	-	0.2-5.1	0.6-3.6

The overall annual input of oil to the North Sea has been estimated at 1.4 million t per year, of which 41 per cent comes from urban run-off and other freshwater inputs, and 22 per cent comes from shipping and terminal operations. The range of petroleum hydrocarbons in the "clean" water offshore in the North Sea was

reported to be 0.5-2.5 ug per litre. Surface waters around drilling rigs were found to have concentrations of up to 18 ug per litre, and in the Thames estuary, concentrations ranged up to 7.1 ug per litre. Sediments in "clean" offshore areas had hydrocarbon concentrations of 1-4 ug per gram dry weight, but near some oilfields they ranged up to 12 ug per gram, and in estuaries where there are regular discharges of oily wastes, concentrations as high as 1 mg per gram dry weight have been measured. Concentrations of n-alkanes in fish muscle from the North Sea ranged from 0.1 to 1.7 ug per gram and in invertebrates 0.1-16 ug per gram wet weight of flesh. Mixed plankton gave values higher than in fish by an order of magnitude in open-sea samples and by a factor of 25 to 50 in coastal waters.

Under normal operating conditions of nuclear power stations and fuel reprocessing plants, discharges are not expected to increase radionuclide concentrations in the North Sea significantly above background levels. Present traces of radionuclides in the area come from the outside, mainly from Windscale and Dounreay, affecting the northern North Sea, and from Cap de la Hague, affecting the southern North Sea.

Despite these various inputs, some of which are of considerable magnitude, the extent of pollution in the North Sea is not large. It can be concluded that adverse effects are confined mainly to coastal areas with "hot spots", such as dumping grounds and polluted estuaries. There is evidence of elevated levels of metals in fish and shellfish on or near certain dumping grounds in the North Sea, but generally the levels found are not much higher than in most specimens from the coastal zone. Studies on the distribution of abnormal fish are beginning to suggest an association with areas of lowered environmental quality. Investigations of the dab, Limanda limanda, for example, caught in the area generally subject to titanium dioxide dumping in the German Bight, have suggested that epidermal papilloma and related lesions may be higher in the dumping zone. There has been no detectable effect on marine fish populations due to pollution, even in those areas of the North Sea which are subject to the highest inputs of contaminants. However, shellfish stocks in some estuaries have probably been affected. Additionally, seals and porpoises living in some parts of the Waddensea have high concentrations of PCBs and mercury in their tissues, and populations of these mammals have been declining continuously in recent years.

As in the Baltic Sea, ICES has co-ordinated many of the pollution studies conducted in the North Sea and in the North Atlantic. Monitoring and more basic scientific studies are being continued and the results are reported in the ICES Co-operative Research Report Series.

The Mediterranean Sea

The Mediterranean Sea (including the Black Sea) has an area of 3×10^6 km^2, which is 0.8 per cent of the total area of the oceans, and a volume of 4.25×10^6 km^3. It has a mean depth of 1,430 m. The continental shelf is generally narrow except in the Adriatic Sea, the northern coast of the Black Sea, the eastern Spanish coast, the Golfe du Lion and between Corsica and Tuscany. Virtually enclosed, the Mediterranean's only connection with the Atlantic is through the Strait of Gibraltar, a constricted opening 50 km in width and 300 m in depth.

The Mediterranean receives drainage from a number of rivers in Europe and Africa. There is a net inflow from the Black Sea of 6×10^3 m^3 per second and precipitation varies from 13×10^3 m^3 to 33×10^3 m^3 per second, but on an annual basis, evaporation exceeds precipitation and run-off, and there is an inflow of surface Atlantic water through the Strait of Gibraltar of 40 and 75×10^3 m^3 per second.

The surface salinity of the Mediterranean is high, and in the open sea it increases from west to east, with summer salinities ranging from about 38.5 to 39.1º/$_{oo}$. The surface circulation exhibits a net eastward flow along the African coast and a net westward flow along the European coast, with a series of counter-clockwise eddies in the Aegean, Adriatic and Tyrrhenian Seas.

Because of its narrow continental shelf and great mean depth, the Mediterranean is generally nutrient poor and primary production and the fisheries yield are low. In 1979, the total fish catch was 1.3 million t, which was 1.8 per cent of the world catch. The species taken in greatest abundance are sardines and anchovies, and most of this catch comes from the Black Sea.

The metal that has been the subject of greatest concern is mercury, which has exhibited high concentrations in several commercially important species, including the bluefin tuna (up to 4 ppm), striped mullet (up to 6 ppm) and the Norway lobster caught far away from anthropogenic mercury sources. These high mercury levels in fisheries products exceed the limits legal in many Mediterranean countries, and enforcement of these limits would lead to the confiscation of a large part of the catch. Elevated mercury levels have been found in the blood and hair of critical groups such as fishermen, fish vendors and their families, and although no adverse health effects have been observed, the potential risk of these high levels has still to be assessed. High arsenic levels have also been reported. Most of these high mercury and arsenic concentrations are considered to be derived from natural sources.

Eutrophication has been observed in many parts of the Mediterranean but it is generally a very local problem mainly caused by improper sewage disposal. The continental shelf of the Mediterranean is for the most part very narrow and thus dispersion into deeper waters is relatively easy. However, in a few areas the eutrophication is of regional importance. Probably the largest area affected is the shallow northern Adriatic which receives large amounts of organic wastes and nutrients directly through the sewage outfalls of coastal cities and indirectly through the Po river. The anticlockwise circulation moves these wastes along the Emilia-Romagna coast where algal blooms are frequent and occasionally mortality of benthic organisms has been observed. It has been estimated that the phosphate level in the wastes has to be reduced by 80 per cent to prevent these blooms.

Sewage also contains a full spectrum of enteric micro-organisms excreted by the population in which many cases of clinical and subclinical enteric diseases often exist. While the commonly used indicator organisms (faecal coliforms) are excreted in fairly constant amounts the incidence of pathogens depends on the number of clinical and subclinical cases. Owing to its climate and socio-economic conditions the Mediterranean has a higher incidence of bacterial, viral and parasitic enteric cases than, for example, northern Europe. For instance, typhoid is about 100 times more frequent in the Mediterranean than in northern Europe. The higher frequency of pathogens in sewage-contaminated waters and the longer immersion of swimmers in the warm water will considerably increase the risk of infection. A greater risk possibly results from the consumption of mussels. The cholera outbreak in Italy was most probably caused by infection from these organisms which are thought to have been contaminated through sewage discharge or releases from ships into illegal mussel beds.

Oil transported through the Mediterranean accounts for 13 per cent of all oil transported globally. About 1 million t of various oils are discharged annually into the Mediterranean. Recent analyses of data on surface oil globally show the Mediterranean to be among the more contaminated areas.

West Africa

The area considered here extends from the coast of Western Sahara in the north to Namibia in the south. The continental shelf in this region is generally narrow and a number of submarine river canyons, such as that of the Congo, incise the outer continental shelf and slope. There are ten major rivers and numerous streams draining into these waters, but only a few, (e.g., the Niger) enter the sea through a highly developed delta system. The shoreline includes many stretches of sandy beaches some of which border mangrove swamps.

The Gulf of Guinea is affected by the three equatorial current systems: the westward-flowing North Equatorial Current coming out of the Canary Current, the eastward-flowing Equatorial Countercurrent and the South Equatorial Current emerging from the Benguela Current flowing from the south. As a result of the winds and ocean current systems, there are areas of seasonal and of permanent upwelling, where nutrients brought into the surface layer contribute to high productivity. The two major upwelling areas are in the Benguela Current system off the coast of Namibia and the Canary Current area off the coast of Western Sahara.

Among the commercially important fish in the northern upwelling zone are such pelagic species as sardines and trumpet fish, sardinellas, horse mackerel and scads, as well as demersal species such as sea breams and hake. Crustaceans, octopus and squid are also abundant and intensively fished. The area of the Gulf of Guinea between 10°N latitude and the Congo River is less productive, except in areas of seasonal upwelling. Pelagic fish resources include sardinellas, bonga, horse mackerel and scads, but their potential is less than in the northern area. Demersal species have a potential of 300,000 t annually. Surface schools of yellowfin tuna and skipjack occur relatively close to the coast. The present annual catch estimated by FAO's Fishery Committee for Eastern Central Atlantic Fisheries (CECAF) is 3.5 million t.

The most important mineral resources of the region are oil and gas which are exploited in Gabon, Congo, Zaire, Angola, Cameroon, the Ivory Coast and Nigeria, the latter being the area's largest producer (4 per cent of world production in 1970-74).

Marine pollution in the region arises from petroleum transport, industrial wastes, domestic sewage and agricultural wastes. Some oil pollution arises from local exploration, exploitation, refining and routine handling of petroleum at ports. But most of the contamination by petroleum originates from heavy maritime transport of crude oil through the region, as a result of the discharge of ballast water from tankers, accidental spills and tank washings. Tar balls on beaches reached a maximum accumulation in 1973-74, with a subsequent decrease in 1975 following the reopening of the Suez Canal and the re-routing of tankers.

Industrial wastes are discharged into the sea, without treatment, from assorted manufacturing operations for such products as sugar, soap, beverages, textiles and wood pulp, and from extractive industries, such as those for aluminium and iron. Domestic sewage and household refuse are frequently dumped into the sea, on beaches, and into coastal lagoons. They create amenity problems that interfere with recreation and tourism. The extent to which they pose biological and health problems is not known.

Agriculture is an important economic base for all countries in the region. Fertilizers and pesticides are used widely, but little is known about their impact on the marine environment.

The Gulf of Mexico

The Gulf of Mexico is a relatively shallow oceanic basin located at the south-eastern boundary of North America. The basin is semi-enclosed and encompasses about 1.7 million km^2. A number of major American, Mexican and Cuban cities surround the Gulf, and several major rivers including the Mississippi drain into it. The Mississippi carries almost two thirds of the total dissolved and suspended solids transported to the ocean from the United States, and, since it drains America's industrial and agricultural heartland, it must also carry a large percentage of the contaminants that enter the oceans from that country. The following additional facts on the region emphasize the potential for pollution of the marine environment of the area (from French; 1981):

- 65 per cent of the total 1975 US crude-oil production was from Gulf coastal States, and a large portion of this was offshore. This constitutes almost 15 per cent of the world's offshore production and comes from more than 2000 fixed offshore structures, or two thirds of the world total.

- A major development of Mexico's petroleum reserves is occurring on the Yucatan Peninsula and offshore in the Bay of Campeche. Some experts estimate that reserves in this area exceed those of Saudi Arabia.

- The western Gulf produced 60 per cent of US sulphur in 1972.

- Crude-oil refining capacity of the Gulf coast refineries was 37 per cent of US capacity in 1977 with a capacity under construction which, when operational, will bring the total to 58 per cent of the US total.

- In 1972, Gulf coast chemical plants produced 40 per cent of every basic petrochemical and 80 per cent of US synthetic rubber.

- Sixteen Gulf coast ports, including the United States' second and third largest (New Orleans and Houston respectively), handled 622 million tonnes of freight in 1977; over 50 per cent of this tonnage was petroleum and petroleum products.

- 33 per cent of the US commercial fish catch (1.75 billion pounds annually) is caught in the Gulf, with a similarly important catch taken by Mexico. The annual dollar value of this US catch is $389 million, and the income from the recreational fishery is considered to be at least as great.

- The coastline and coastal waters of the Gulf serve as a recreational area for a significant portion of the US and Mexican populations. Building of new recreational facilities along the coast is proceeding rapidly.

- Population growth in the five US Gulf coast States has exceeded all previous projections. The present rate of growth is expected to continue till the year 2000 with a concomitant increase in industrial development and urbanization.

When the above facts are considered in conjunction with the natural setting of the Gulf of Mexico, especially its semi-enclosed structure and the nature of water movement within it, a real concern over the extent and potential increase in pollution of the area seems justified. It is not yet clear whether the impact will be immediately and obviously harmful to the marine ecosystem, or be too subtle to assess or even detect in the short term. Many of the environmental problems of the Gulf region are common to other geographic areas, while others are related to the unique character of the region itself.

North American Coastal Waters

The North American coastal waters are considered in three broad regions (1) Atlantic; (2) Pacific; and (3) Arctic.

Atlantic Region: Several rivers run into the Atlantic along the eastern seaboard of the United States and Canada, the main freshwater source being the St. Lawrence which drains the highly populated and industrialized States on the American side of the Great Lakes and the slightly less populated and industrialized areas on the Canadian side. Other sizable and polluted rivers, such as the Hudson, Delaware, Susquehanna, Potomac and James rivers discharge into Atlantic coastal waters.

Except for the extreme southerly section of the Atlantic Coast of North America, positive estuarine circulations prevail most of the year. The tidal range decreases from north to south, with a range of more than 9 m at the head of the Bay of Fundy, to less than a metre in the Gulf of Mexico.

The eastern seaboard of North America is heavily populated almost from the Canadian border to the southern tip of Florida. There are population centres, separated by considerable distances, on the Canadian side in the maritime provinces and in Quebec along the St. Lawrence estuary.

Although the Atlantic coast of North America is not a major maritime route for the transport of oil, there are occasional tanker accidents with a substantial amount of oil spilled. Petroleum refineries are scattered all along the Atlantic coast. They typically have oily discharges which can contribute to oil slicks and other undesirable conditions in receiving waters. Normally however, oil concentrations are relatively low (<10 ppb) in sea-water along the Atlantic coast of North America, even in some of the more confined marginal seas, such as the Gulf of St. Lawrence.

The dense populations of the east coast of the United States and in parts of Canada contribute a substantial volume of sewage, which reaches coastal waters via direct outfalls or through rivers after varying degrees of treatment. This may have undesirable effects in a number of ways. Living resources have been affected in some areas by sewage discharges. Oyster production can be affected by over-fertilization and excessive algal growth, as demonstrated in Great South Bay of Long Island by excessive input of nutrients from duck farms. Frequently however, oysters are simply rendered unmarketable due to their accumulation of faecal coliforms to levels which exceed those set by North American health standards.

Disposal of assorted wastes by ocean dumping off the east coast of North America has included low-level radioactive wastes, industrial wastes, sewage sludge and dredge spoils. Dump sites off the New York Bight have been used for a long time and concern has been expressed about the ecological damage that dumping in this area is causing.

Metal-containing wastes from such operations as electroplating and metal-processing plants are discharged from most urban centres along the Atlantic coast of North America. In the Canadian maritime provinces, metals are released from mines and smelters. Leaching of lead and zinc from mine tailing piles in the Miramichi River drainage basin has affected the important Atlantic salmon run in this stream.

Chloro-alkali plants using mercury cells and pulp mills using mercurial slimicides contributed mercury to some of the streams and coastal waters of the Canadian maritime provinces and Quebec before 1970. Action was taken to stem these

sources in 1971 and the discharges of mercury are now very low. However, sediments continue to exhibit high mercury concentrations in some areas.

Other problems on the Atlantic coast are due, for example, to logging, sawmills, pulp and paper mills and other forest products operations. Particulate wood solids settle on the bottom near these mills, changing the benthic ecology. The dissolved organic constituents have a high biochemical oxygen demand and deplete the oxygen content of receiving waters. Some of the inorganic constituents and especially the sulphur-containing compounds, are toxic to aquatic life. In general, the effects from pulp and paper mills are local.

Pacific Region: The coastal configuration of the Pacific coast of North America varies from the convoluted fjord coastline, fringed with islands of southern and south-eastern Alaska and British Columbia to the rather exposed, relatively unindented coastline of the States of Oregon and California, Mexico and Central America.

The Pacific coast tidal range increases from south to north, with a range of nearly 10 m during extreme tides in the inlets of south-east Alaska. The tides contribute to strong currents and mixing in many of the coastal inlets, bays and channels.

In general, the Pacific coast of North America is less industrialized than the Atlantic coast, and the population density is also lower except in the Greater Los Angeles area. Although at one time it was feared that the large volumes of sewage discharged from this area were destroying the kelp beds of the Southern California Bight they now appear to be recovering in spite of continuing and increasing sewage discharges. One problem that has been associated with the sewage outfalls is fin rot in bottom fish. However, despite continuing study, the cause-effect relationship of this phenomenon has not yet been fully resolved.

Industrial discharges stem largely from forest-product industries and metal-processing plants in the area of Puget Sound in Washington State. Most pulp and paper mills have secondary treatment for their effluents, and this has been generally regarded as one of the cleaner marine areas in the United States.

Along the coast of British Columbia and south-east Alaska, there are numerous pulp and paper mills, and most discharge their effluent without treatment into coastal waters. The problems created in receiving waters are generally local, but can affect fisheries if effluents are discharged into rivers or estuaries carrying important runs of salmonids. The mining industry also gives rise to some pollution.

Arctic Region: The Arctic Region represents the cold environment of North America which is frozen over for most of the year from October until July and is impassable for most vessels except with the assistance of ice breakers. Pack-ice is present in virtually all areas during this period. Icebergs which break out of glaciated fjords on the west coast of Greenland and the Canadian Arctic islands during the spring and early summer present a hazard to gas or oil rigs which operate offshore at that time of year.

The human population is small in the Arctic and there are no land-based industries to speak of. However, there is the prospect of oil and gas exploitation in the Canadian Arctic, and the Prudhoe oil field on the north slope of Alaska has been in operation since 1977. Exploration has been active since 1960. Exploration has been particularly intensive in the Beaufort Sea. There has always been concern about the effect of a major oil spill on the fragile Arctic ecosystem.

South-West Atlantic

The South-West Atlantic, which includes the Brazil Basin and the Argentine Basin, is a very extensive region, with highly populated as well as almost unpopulated areas. Industrialization is at a relatively early stage, having started about 70 years ago.

Two of the most important rivers in the world enter the coastal area of the region. First the Amazon River system drains an immense area of the South American Continent with little population and no polluting industries or large urban centres. It carries a large amount of natural substances from inland and its influence is felt far into the ocean. Second, the Rio de la Plata system is also very extensive. Among its sources are the following rivers: Rio Grande, Paraguay, Pilcomayo, Bermejo, Parana, Salado and Uruguay, and five countries are within this system: Brazil, Bolivia, Paraguay, Argentina and Uruguay. It is used as an international waterway. It carries from inland a large amount of natural and man-made substances from the most populated and industrialized area of South America. The river is known to be polluted and its influence is detectable on the wide continental shelf.

The greatest population densities in Brazil, Uruguay and Argentina are located on or near the Atlantic coast. They are concentrated in relatively well defined regions around a few cities that also have highly industrial activities.

Municipal wastes cause only minor problems, except in three areas. One of these is the corridor from the city of Natal (Rio Grande do Norte, Br) south to Salvado (Bahia, Br), where the coast has more than 50 inhabitants per km^2, one of the highest in South America. The second is the coast of the Brazilian States of Rio de Janeiro and Sao Paulo, with a total population of more than 10,000,000 directly or indirectly related to the coast. In the third, the mouth of Rio de la Plata with the capital of Uruguay, Montevideo, on the coast, there is, directly or indirectly, the effect of about 15,000,000 persons living in the area.

Although local in character, the Lagoa dos Patos connected to the sea near the city of Rio Grande, is in itself an important centre of municipal wastes with the cities of Porto Alegre and Pelotas on its coast.

There are important concentrations of heavy industry in the region. One is on the coast in the region of Santos/Volta Redonda/Sao Paulo, with oil refineries, chemical and petrochemical factories, iron and steel mills. The other is inland, but affects the coast through the Rio de la Plata discharge. The heavy industry of Argentina is inland on the coast of the Parana River (Rosario, Zarate) and on the west coast of the Rio de la Plata (Buenos Aires, Gran Buenos Aires, La Plata). The main industrial activities are oil refining, chemicals, steel mills, paper mills and food processing.

The most important (actual and potential) source of marine pollution in the entire region is oil/gas exploration/exploitation on the continental shelf, offshore from the States of Rio de Janeiro and Sao Paulo in Brazil and offshore from the San Jorge Gulf in Argentina.

The South-East Pacific Coast

The South-east Pacific Coast extends approximately 1,400 km and includes three countries: Ecuador, Peru and Chile, with a population of more than 32 million. Climate varies from tropical in the north to very cold at the tip of South America.

The main inputs considered as dangerous for the marine ecosystem are domestic

and industrial discharges, pesticides, and oil and petrochemicals. There are few plants for sewage treatment in the region and many towns and industries discharge directly into the ocean or to rivers. Serious pollution is unlikely to be present in large areas because of the open geographical location of the three countries, and the relatively low urban and industrial concentrations.

In Ecuador the most seriously polluted areas are the Guayas estuary (including the largest city, Guayaquil), Esmeraldas and Manta. Discharges from land, and oil spills, are the main sources.

Peru's coast is polluted in many localized areas by domestic and industrial discharges, generally where towns are located. Some oil spills have occurred particularly from drilling platforms. Ite Bay is a typical example of pollution by mining wastes and Chimbote Bay, of organic pollution from fishing plants.

Chile presents a similar picture regarding inland discharges and mining wastes, for example in Chanaral. The Magellan Strait, a fragile ecosystem, has suffered heavy oil spills and is a potentially endangered area because of oil pollution. Little research, control or monitoring of marine pollution has taken place in this region although some studies have been done on oil spills and sewage discharges.

Fishing is a major activity in the three countries. This provides not only for direct human consumption, but also for canning and fishmeal in Peru and Chile. Shrimps and molluscs are important resources in Ecuador, northern Peru and Chile where they are captured, generally near shore. Peru's per capita consumption of fish is approximately 18 kg per year, about 74 per cent of the meat consumption. The 1979 Peruvian fish yield was 3,580,000 tonnes, of which 2,850,000 were used for fishmeal, the remainder going for human consumption, distributed mainly between three species: anchovy with 1,880,000 tonnes (66 per cent); sardine with 910,000 tonnes (32 per cent); and mackerel with 60,000 tonnes (2 per cent). This yield represents a serious decline of 30 or 40 per cent of the catch during peak years of the 1965-1975 decade, although this cannot be attributed to pollution.

The Indian Ocean

The Indian Ocean stretches from the Gulf of Oman and the head of the Bay of Bengal in the north to the East African Coast, in the west, and to the coastlines of Burma, Thailand and Malaysia (excluding the Straits of Malacca), in the east. The tidal range varies from 1 to 8 m and there is a twice-yearly reversal of monsoon winds and surface currents. These help considerably to reduce the impact of pollution by dilution and dispersion and even affect bottom currents and settlement of suspended material.

Nineteen countries border the Indian Ocean. Their total area is about 9.6 x $10^6 km^2$ and they are inhabited by some 950 million people. The average population density is 99 per km^2.

Agriculture, industry, and in some cases mining, form the economic base of countries surrounding the Indian Ocean. Effects of pollution in the marine environment from these activities have begun to appear. These effects are so far confined to coastal areas, but owing to the prevailing wind system, the water circulation pattern, and the bottom topography, they may have far-reaching consequences on several countries.

Owing to increasing urbanization and industrialization all over the region, the volumes of sewage and effluents along the coasts are increasing. Many countries have large rivers flowing through them and many are badly polluted. Substantial

sewage effluents are discharged untreated or after only primary treatment. However, no depletion of fish stocks or large-scale mortality have been recorded so far, although periodic fish mortality has been reported from some of the countries.

Aesthetics represent another problem in these countries. Hardly 50 per cent of the total population in this area has sanitation arrangements. Large coastal areas are exposed, owing to tidal fluctuations twice a day, and during low tide these places become very unpleasant. In many countries, high coliform counts are often reported from coastal waters.

Concentrations of toxic metals, like mercury, copper and lead in plankton and fish are still much lower than levels recorded in many industrialized countries.

Fertilizers, pesticides and insecticides are abundantly used in countries round the Indian Ocean, in agriculture, pest control and disease-vector control. The quantities of pesticides used annually vary from 40,000 metric tonnes in India to 3.5 metric tonnes in Bangladesh (NIO 1976). In many countries, however, organochlorine pesticides are either totally banned or are gradually being replaced by organophosphorous and carbamate pesticides. Although no detailed study of their accumulation and harmful effects has been carried out, efforts are slowly being increased and a survey has indicated that plankton in the Arabian Sea, off the Indian Coast, has DDT concentrations ranging from 0.05 - 3.21 ppm wet weight (Kureishy et al. 1978).

In countries of the region, power generation is mostly thermal, but some nuclear power is generated. So far, no harm has been reported from these sources. Radioactive wastes are disposed of in conformity with international convention. Wherever coal is used in the thermal power plants, the fly ash creates problems in the environment but experience with cooling water discharges suggests that if properly sited these do not cause a problem.

Tourism is being promoted in all the countries of the region. Large modern hotels have been constructed on the sea shores. In some countries like the Seychelles, Mauritius and Sri Lanka, refuse from such hotels has spoilt some of the beaches. Waste waters also cause problems, at times generating hydrogen sulphide in water.

Oil pollution is a chronic and sometimes acute problem in and around the harbours of all the countries in this region. In 1979 the global marine transport of oil was 1,750 million tonnes, 58 per cent of which was shipped from the Middle East countries (BP 1979), much of it across the Arabian Sea. One of the main routes is through the Mozambique Channel round South Africa to the Western Hemisphere, while the other is round Sri Lanka across the southern Bay of Bengal through the Malacca Strait to the Far East and Japan. This, coupled with the increasing emphasis on offshore oil exploration in many countries of the region, makes the northern Indian Ocean very liable to oil pollution. Fortunately, few tanker disasters have so far occurred along these routes. The effect of oil spills is seen on the beaches of every country in the form of deposits of tar-like residues. The frequency and intensity depend on the current patterns along the coasts. The amount of floating tar in the Arabian Sea has been estimated at 3,700 tonnes, and about 1,100 tonnes along tanker routes across the southern Bay of Bengal. This is roughly proportional to the difference in tanker traffic.

Coral reefs and mangroves occur widely in almost all the Indian Ocean regions and are important to the economy of many regions. Damage can occur to them due to over-exploitation and effects of pollutants.

The growth rate of Indian Ocean corals may be assumed to be of the same order as that of corals in the Atlantic, about 0.15 - 0.5 cm per year. Several reefs have almost disappeared, owing to their exploitation to supply raw material to the cement industry. Some reefs have died owing to the impact of pollutants, particularly oil from spills. Examples of this are the Kavaratti reef in the Laccadives; the southern part of Great Nicobar Island in the Andaman group, and the south-western part of Madagascar. Dredging for harbour construction has destroyed some coral reefs of the Mahé island in the Seychelles.

Mangroves constitute a diverse resource in the region, they contribute to nutrient supplies, and are important spawning grounds, nurseries and feeding grounds for economically significant aquatic species. They provide protection to sensitive communities like coral reefs, and control the characteristics of bottom sediments, local mean water level and water courses. Mangroves constitute a substantial part of many countries and a significant part of the population is dependent on them. For example, one-eighth of Bangladesh is mangrove land and one-third of the total population of the country is dependent, directly or indirectly, on this mangrove environment (UNESCO 1979).

The Indian Ocean receives about 34×10^8 tonnes of suspended sediment annually, of which about 16×10^8 tonnes come from the rivers flowing through the Indian sub-continent. This quantity is increasing owing to human activities, such as sea-bed and terrestrial mining, land clearance for agriculture, lumbering, urbanization and dredging to deepen harbours and estuaries. Most of this silt settles near the river mouths and in the coastal areas. This can be expected to reduce productivity and deplete fisheries. These effects have been felt in many countries, but no attempt has yet been made to establish a direct correlation between siltation and fisheries.

Australian Coastal Waters

Australia is a federation of six States and two Territories, with a number of external Territories. The Constitution provides for certain powers to reside with the Federal Government and all others fall to the States. Environment protection resides largely with the States, except for the assessment of environmental impacts of proposals requiring export or other Federal Government approval, and those areas covered by international conventions. Recent Australian legislation provides for State responsibilities to the three-mile limit, while the Commonwealth retains offshore rights to the internationally agreed fishing zone with joint responsibilities for fisheries and mineral development.

Major studies have been carried out, by the Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Fisheries and Oceanography, on both the eastern and western coastal systems. The general picture of ocean circulation, based on studies of the North Pacific and North Atlantic, is not reflected in the systems described for Australia's coasts to the Indian and South Pacific Oceans. The east coast is characterized by large eddy systems rotating anticlockwise with diameters of 200-300 kilometres and maximum surface velocities of 3.5 - 4 knots. Individual eddies may have a lifetime of at least one year and they have a southerly drift which may be interrupted or reversed for short periods of time. There is no clearly definable southern stream.

On the western seaboard, there is at times a net northerly transport of water which is also characterized by large eddy structures. However, detailed work has indicated that a southerly set may prevail for part of the year. In late autumn a strong pulse of warm fresh tropical water moves south along the continental shelf and slope.

In the north, in the Gulf of Carpentaria, a clockwise flow has been detected by satellite-tracked buoy. In the south a seasonal rhythm with a summer-winter alternating system has been proposed.

Available pollution data are largely from the nearshore waters or coastal inlets of Australia located near major cities, where most of the pollution studies to date have been carried out.

Published data indicate localized pollution in a number of areas. Corio Bay, the Derwent estuary in Tasmania, Cockburn Sound in Western Australia, and the Brisbane River estuary are typical of environments near major industrialized cities. Botany Bay and the Parramatta River estuary at Sydney, NSW, are not listed, more due to lack of reported measurements than to their cleanliness. This must also be true of a number of other locations around the coast of Australia.

Two areas, the Derwent Estuary in Tasmania, and Corio Bay in Victoria's Port Phillip Bay, show indications of heavy pollution, while Hobsons Bay, also in Port Phillip Bay, shows indications of medium to heavy pollution.

New Zealand Waters

New Zealand comprises three main elongated islands and several small, mostly uninhabited, offshore islands. The country lies in the South Pacific with the northern island extending to about 34°S and the southern island to about 47°S. The climate ranges from subtropical in the north to subantarctic in the south. Its coastline is about 8,000 km long and the islands act as a barrier to the general eastward movement of the water in that part of the South Pacific. Part of the warm subtropical water of the East Australian Current System passes around the North Cape of the North Island giving rise to the East Auckland current. Anticyclonic eddies from this subtropical current flow south along the coast of the North Island. There is also the Westland Current, arising from the subtropical Tasman Current which flows northward up the west coast of the Islands. These major current systems are in general better known than the shallow water circulations close to the coast.

New Zealand has a population of only 3.2 million, about two thirds of which lives in coastal communities. The economy is largely agricultural and most of the marine pollution problems arise in connection with domestic sewage and wastes from industries producing agricultural products. About 77 per cent of the population is served by piped sewage systems and although these often discharge to estuaries, harbours and coastal waters they are not believed to place any excessive burden on the assimilative capacity of the environment. However, although the human population is small, the animal population of the country is in excess of 250 million human equivalents, and the wastes from the many factories processing meat, milk, butter and cheese and other animal products such as leather and wool do give rise to effluents with high organic loadings.

The agricultural economy also gives rise to other discharges which might affect the quality of coastal waters. Fertilizers are used in substantial quantities (superphosphate 2.6 million tonnes; lime 1 million tonnes and nitrogen fertilizers 20,000 tonnes annually). Some of these fertilizers are produced in factories which discharge effluents to coastal waters. Pesticides are also used extensively although some of the more persistent compounds such as DDT are no longer permitted.

Oil pollution is not a serious problem in New Zealand. The country is well away from the main tanker routes and there is only one oil refinery sited in the North Island. Transport of oil is therefore mainly crude to this refinery or as oil products from it for domestic use. Spills so far have been on a small scale only.

There are no major industrial discharges containing metals and no operating metal-ore mines. However, arsenic arises in the water from geothermal developments. There is one aluminium smelter in the North Island and one is planned for the South Island, and fluorides are thus discharged both to the air and in their liquid effluents.

Fishery production has increased in recent years and now amounts to 60 - 80,000 tonnes/yr. Since adoption of a 200 mile EFZ in 1978 the catch has included an increasing proportion of deep water species such as skipjack tuna. Catches of rock-lobster, mainly in coastal waters, have declined in recent years but this is believed to be due to fishing pressure rather than pollution. Generally, the levels of pollutants found in marine organisms have been found to be low, except close to known pollution sources, e.g. average mercury in snapper (30 per cent of catch 1975) was 0.25 mg/kg.

CHAPTER VII

METHODOLOGY FOR THE ASSESSMENT AND
CONTROL OF MARINE POLLUTION

VII.1 Introduction

In order to provide a basis for the assessment of marine pollution, it is pertinent to consider the implications of the GESAMP definition of marine pollution; namely, "Introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairing of quality for use of sea-water, and reduction of amenities." Implicit in this definition is the understanding that:

(i) marine pollution is caused by the introduction into the marine environment of substances and energy which have adverse affects;

(ii) marine pollution can be related to its sources, it is created by man and can, in some instances, result in the increased flux of substances in existing natural cycles;

(iii) polluting substances are dispersed through the marine environment by various processes, whereupon they affect organisms including man, particularly as a user of the ocean systems;

(iv) the significance of the pollution depends upon its effects on different targets, and social values are often involved;

(v) the quantification of the effect and hazard of pollution is a question that must usually be answered before a judgement can be made of whether or not pollution is acceptable.

The definition and its implications give guidance on how to answer the question: What do we need to know to be able to carry out an assessment of marine pollution; that is, to assess the "health" of the oceans?

Information must clearly be available on:

(i) sources of substances and energy, their existing and predicted quantities, and their distribution in the environment;

(ii) the processes leading to dispersion in the marine environment, where substances from a particular source will go, and what targets may be affected;

(iii) effects of pollution on various targets and the significance of these effects.

The information presented in the previous chapters is relevant to these three areas.

The existing data base for an assessment of global marine pollution is extremely limited, although for some local geographical regions it is substantial, especially regarding the input and distribution of contaminants. One aim of any assessment should be to relate levels of inputs to effects in the environment. This often depends on knowledge of the dose-response function of targets affected by the contaminant in question. Unfortunately much of the available information on dose-response functions has been obtained by laboratory studies where considerably higher concentrations of the substance have been used than will be encountered in the environment.

An attempt is made in the following sections to present the basic principles and limitations of currently-applied assessment techniques.

VII.2 Environmental data base

A basic requirement for the assessment of the extent of marine pollution is a reasonably well organized data bank on the conditions in the environment. The data bank can consist of:

(i)   data on input of contaminants, including information on the distribution of sources and the quantities introduced to the region in question;

(ii) data on the natural conditions in the region as regards physical, biological, and chemical oceanography, sedimentary conditions, and river run-off;

(iii) information on the interaction between the contaminant and the marine environment including, for example, information on the geochemical or biological processes which may lead to its removal from the marine environment or concentration in parts of it;

(iv) information on concentration levels in various compartments of the environment, for instance obtained through a co-ordinated baseline study whereby samples are collected in an agreed way and analysed by means of common and intercalibrated analytical techniques.

In many instances some elements of this data base are not available. This may arise because the complexity of the system or the cost of observations make them impractical to obtain or because there is a lack of understanding that a potential pollution hazard exists. Depending on the nature of the expected hazard or of the marine environment affected, it may be most effective to concentrate on obtaining some elements of the data base. In some instances, for example, it will be difficult to obtain information on inputs and be easier to infer them from measurements of environmental concentrations and knowledge of the important environmental processes. In other cases it is more efficient to concentrate on measuring inputs and environmental effects. In general, however, some information on all elements of the data base will be necessary.

Base-line studies may identify areas within a region, often referred to as "hot spots", where elevated concentrations of a contaminant occur. These may require periodic surveillance or monitoring and better information on the rate of input of contaminants to the region.

VII.3 Environmental capacity

It has been stated earlier that the oceans have a finite capacity to receive
many contaminants. The "health" of the oceans must to some extent depend on whether
or not the limit of this capacity is being approached. Unfortunately, the
methodology for the determination of such a capacity remains complex. One way of
establishing an environmental capacity rests with determination of the target(s)
most at risk as a result of the input of a contaminant and the use of standards
appropriate for their protection (Goldberg 1979; Preston 1979). The environmental
capacity may then be defined as that rate of introduction of the contaminant which
will not result in a rate of exposure to the target that exceeds the established
standard. The exposure routes and targets are known as the critical pathways and
critical targets. This approach to obtaining an environmental capacity has been
used extensively in the field of radiation protection, with man as the usual primary
critical target.

The utility of this approach for regulating the release of a contaminant
depends on several key features. It must, for example, be possible to identify the
critical pathways and targets. The latter may be generalized to include, where
necessary, effects on organisms in the marine ecosystem, the health of the ecosystem
itself, aesthetic effects, etc. This aspect is further discussed in the next
section. Calculation of relationship between the input of a contaminant and its
effects on a critical target must usually rely on considerable understanding of the
transfer of the contaminant through the various pathways in the system and on the
construction of a model representation of this transfer. The fluxes in the ocean
environment including those across the land-sea, air-sea, and sediment-water
interfaces discussed earlier in chapters II and III will be one aspect of such a
model. In some cases, e.g., short-lived radionuclides, when the important processes
are known to be uniform in time, the distribution of a contaminant and knowledge of
its input may be sufficient to form the basis of a calculation of an environmental
capacity. In other cases, e.g., long-lived radionuclides, where a number of
different processes that have time scales longer than the period of release are
often important, calculation of the environmental capacity will require knowledge of
the primary processes.

Implicit in the concept of environmental capacity is that there is some level
of contaminant, perhaps a threshold for a significant effect, which must not be
exceeded and that such a level (or levels in different parts of the system) will
limit the environmental capacity. In many situations, however, concern over
sub-threshold or sub-lethal effects result in the desire to keep the level of
contaminants in the environment as low as is reasonably achievable. This can be
implemented only through the use of a cost/benefit or cost/risk type of assessment.
In radiation protection this approach is taken formally into account by attempting
to keep the health detriment as indicated by the collective dose commitment to the
exposed population as low as possible, bearing relevant social and cost/risk factors
in mind. There are as yet insufficient data to apply such an approach to many other
types of pollutants, and especially so outside the context of public health. It
still remains a desirable objective for which the necessary additional data should
be sought. For the time being an alternative way of taking such concepts into
account involves the principle that it is only reasonable to use the ocean for waste
disposal where, after careful consideration, it appears to provide the best overall
environmental option. Among the considerations which will have to be taken into
account before such a conclusion is reached is a careful assessment of the relative
significance of the effects of such disposal on land or at sea. This consideration
of the use of the sea may only involve national authorities but it may on occasion
introduce assessment on a regional or even a global scale. The great variety of
different social and economic circumstances in different regions means that the

acceptability of contaminants in the environment must involve some value judgements. In this report value judgements of this type have been avoided as much as possible.

VII.4 Critical targets and standards for protection

The ideal assessment depends on being able to identify those targets most at risk as a result of the input of a contaminant and on the development of standards appropriate to their protection. Based on an adequate model, these standards may be used to calculate the upper limit of input for a contaminant at which a target is not endangered. The critical target may be man, an element of the marine biosphere, the marine ecosystem, a sensitive geochemical or physical mechanism, or some aesthetic quality whose protection is required for effective regulation of the contaminant in question.

When man is the critical target, the aim of primary standards is to keep human exposure to a toxic compound below an acceptable level. For practical purposes, related to the ease of standardization, regulations usually limit the concentration of a toxic compound or element in products suitable for human consumption, even though the acceptable intake approach (which considers the contribution of a toxic constituent in a certain type of food to uptake from the total diet) is toxicologically more justified. The setting of such a standard may be based on human epidemiological data, or animal experimental data extrapolated to man, or both. The aim is always the protection of the most sensitive population against adverse effects. The standards that limit the introduction of toxic materials into the sea or into products of the sea in order to protect man are usually achieved according to the principles of general toxicology.

While for humans a standard is required to ensure the protection of the most sensitive population groups or at least to decrease risk to an acceptable level, the marine environment is not usually given the same degree of protection. With marine organisms, the primary concern is with the protection of the sea as an ecological system. In this case the starting point for a standard depends on environmental studies, or toxicological experiments, or both. The complexity of the marine environment, the large number of species and the interaction between species make standard setting for the protection of the marine environment as yet a very difficult task.

Although it is often possible to relate the concentration in water or in the food of a given species to effects on a certain percentage of the population under study, the extrapolation of such data to the natural environment may have inherent errors. For example, sub-lethal effects experimentally determined for marine populations may be of sufficient severity to carry with them, when extrapolated to the environment, a high probability of death or reduced reproductive capacity. In the natural struggle for survival, these would have a similar significance for the whole exposed population as relatively prompt direct lethal effects to substantial numbers of individual members of the population.

The direct monitoring of environmental situations to determine the presence or absence of biological effects attributable to pollution is often inconclusive because of the background of normal natural variation. In addition, levels of pollutant concentration likely to be deemed acceptable in the environment will also usually limit the possible observance of environmental effects in unequivocal terms except in the immediate vicinity of major disposal operations. Aquatic experiments which aim not only at the establishment of a dose-response curve for mortality but try to identify morphological or biochemical abnormalities at sub-lethal exposure levels and try to explain the kinetics and metabolism of toxic substances may lead to improved standards for the marine environment in the future.

VII.5 Control of discharges

Once acceptable levels for the introduction of contaminants to the marine environment have been derived, the control of discharges requires some form of monitoring. However, it is customary, and in some cases necessary, because of the nature of a pollutant, to set limits to the rate of release well below those dictated by the use of a standard for a critical target. Monitoring is appropriate for the verification of the model upon which the release rate calculation has been based and for the provision of assurances that the situation is indeed acceptable. It is useful to distinguish between monitoring the rate of input and monitoring the levels of contaminants or their effects in the environment. In some cases more effort has been placed on environmental monitoring than on input monitoring, which has led to the situation where observed levels in the environment cannot be sensibly related to input rates. Verification of a calculated environmental capacity will require monitoring of both inputs and distributions.

Monitoring the levels of pollutants in the environment may start with a baseline survey to establish existing levels. This will be of particular importance where previous introductions of the pollutant have not been preceded by an environmental assessment or accompanied by any necessary controls. Ideally, the objectives of subsequent regular environmental monitoring conducted in the context of regulation should be directed towards the assessment of the actual or potential exposure of the critical target(s) resulting from the introduction of the pollutant. In some cases the objective may be the estimation of the probable upper limit of such exposure. It may be possible on occasion to look for the actual effects of pollution: so-called "biological effects" and "ecological" monitoring (see GESAMP 1980b). The efficient implementation of environmental monitoring programmes is often limited by a lack of understanding of the critical targets and impacts on the population being considered.

Monitoring in this context, which involves the ability to interpret the data obtained in terms of the derived environmental quality standards, will often have requirements different from those needed in equally valid programmes designed to establish spatial and temporal trends. Pollution distributions in the marine environment often provide information on the basic physical and biogeochemical processes which control their spread. Experimental programmes designed to exploit this fact can provide input for the verification of models in use and for the construction of new and better models.

VII.6 The role of international agreements

Although contaminants from coastal point sources have localized impact initially, there may be subsequent extensive dissemination, and this, together with input from land run-off, rivers, ships, and the atmosphere, can result in problems that are not confined to national boundaries. Adequate surveillance and control thus require international agreement and concerted action. Bilateral, regional and international conventions provide a legal framework for such co-operation. An early example is the convention of 1902 which established the International Council for the Exploration of the Sea, a body which now co-ordinates oceanographic activities of 18 countries bordering the North Atlantic.

International environmental law for the oceans must deal with the multiple nature of the problem. The oceans are threatened by pollution and degradation from a number of varied sources, and a strategy to manage the marine environment must be comprehensive if it is to be effective. In addition to providing measures to control pollution, it has been recognized that legal agreements should also encourage States to adopt policies for long-term resource management and conservation.

The progressive elaboration of environmental law has been a direct reflection of Governments' perception of the threats to, and the need for an appropriate strategy for maintaining, the health of the oceans. When discussions on a new ocean regime first began within the United Nations Committee on the Peaceful Uses of the Sea-Bed and the Ocean Floor beyond the Limits of National Jurisdiction (1969), international awareness of the need to manage the resources of the ocean was in an early stage. In the ensuing years, substantial progress has been achieved towards a comprehensive legal regime on environmental protection and resource management.

Since the early 1970s, Governments have continued the negotiations to establish a new legal regime for the oceans under the auspices of the third United Nations Conference on the Law of the Sea (UNCLOS). Although a final, signed legal agreement has not yet been achieved, negotiations of UNCLOS have a bearing on many planned and ongoing marine investigations since they envisage a global policy for ocean management. From the environmental perspective, one of the significant achievements of the conference is the inclusion, in treaty form, of a general obligation of all States to protect and preserve the marine environment as a whole. There are also general provisions and articles drafted on almost all issues of ocean environmental management. While admirable in their general import, those general principles will require a great deal of concentrated and detailed future work, at global, regional and national levels, for their effectuation.

The UNCLOS negotiations have benefited from the legal agreements that had previously been adopted for the purposes of protecting the marine environment. Early international agreements focused on pollution from ships, and in particular, oil pollution. One of the first international marine environment agreements was the 1954 Convention for the Prevention of Pollution of the Seas by Oil. This was the first international agreement concerning prevention of pollution from normal shipping activities.

In 1958, the Convention on the High Seas was adopted. Two articles of the agreement were concerned with the control of pollution. Article 24 of the High Seas Convention calls upon States to "draw up regulations to prevent pollution of the seas by the discharge of oil from ships or pipelines or resulting from the exploitation and exploration of the seabed and its subsoil". Article 25 commits States "to prevent pollution of the seas from the dumping of radioactive waste" and to co-operate in taking measures "for the prevention of pollution ... resulting from any activities with radioactive materials".

Two important agreements concerned with compensation for ship-generated pollution were developed at the International Legal Conference on Marine Pollution Damage (Brussels, 1969): the International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, which allowed States to take necessary measures to prevent, mitigate or eliminate "grave and imminent danger to their coastline or related interests" from oil pollution following a maritime casualty; and the International Convention on Civil Liability for Oil Pollution Damage which provides for compensation from damage and established a limit of liability. The latter Convention was later supplemented by the 1971 Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage.

In the early 1970s, two additional global conventions were adopted aimed at controlling pollution by dumping and ship-generated pollution. The 1972 Convention on the Prevention of Marine Pollution by Dumping of Waste and other Matter groups substances into categories according to the gravity of the risks they present to the marine environment. The dumping of "black" list substances is prohibited while the dumping of "grey" list substances is permitted only after the issue of a specific permit.

The 1973 International Convention for the Prevention of Pollution from Ships (MARPOL) extends the 1954 Oil Pollution Convention to all types of vessel-source pollution, with the objective of eliminating completely pollution of the marine environment by oil and other harmful substances caused by intentional discharges from ships. The MARPOL Convention has recently been extended and updated by a protocol adopted at the IMCO Conference on Tanker Safety and Pollution Prevention (London, 1978).

In parallel with the global agreements, coastal States have co-operated on the regional level to develop agreements for the protection and development of the marine environment. Regional agreements provide States with a mechanism for focusing on specific problems of high priority to the region. On the one hand, regional agreements may permit States to adopt more stringent standards and regulations in the light of the characteristics of the region concerned. On the other hand, regional agreements may more readily take into account the economic, social and cultural priorities of the coastal States concerned, and, therefore, may reflect more realistically the needs and capabilities of the States of the region.

In the North-East Atlantic Region (including the North Sea) three agreements, each dealing with a separate aspect of pollution control, have been adopted:

-       Agreement for Co-operation in Dealing with Pollution of the North Sea by Oil (Bonn, 1969);

-       Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (Oslo, 1972); and

-       Convention on the Prevention of Marine Pollution from Land-Based Sources (Paris, 1974).

In 1974, the States bordering the Baltic Sea adopted the first agreement with a comprehensive scope for the control of marine pollution: the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki, 1974). In the Helsinki Convention, obligations for controlling pollution from various sources are contained in one comprehensive agreement and its annexes.

For the Mediterranean Sea, the coastal States also adopted a comprehensive view of pollution control and resource management, but the format of the regional agreement is different from that of the Helsinki Convention. The Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona, 1976) is an umbrella agreement providing a general obligation to control pollution. Specific technical protocols elaborate obligations to control pollution from a discrete source or to co-operate on some aspect of environmental management. Protocols dealing with dumping, co-operation in pollution emergencies, and land-based sources of pollution have been adopted to-date by the Mediterranean States.

The Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution (Kuwait, 1978) is similar in format to the Barcelona Convention and has been supplemented by a protocol concerning co-operation in combating pollution by oil and other harmful substances in cases of emergency.

The States of West and Central Africa likewise accepted the pattern of an umbrella Convention and related protocols as may be seen from the Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (Abidjan, 1981) and its related protocol on co-operation in pollution emergencies.

The States of the South-East Pacific, the Wider Caribbean Region, and the Red Sea and Gulf of Aden are also co-operating on the adoption of Conventions for their regions similar to the three conventions mentioned above.

The proliferation of regional conventions with a comprehensive objective of protecting the marine environment from pollution whatever the source and of ensuring the long-term management of resources illustrates the importance of regional agreements as a mechanism for elaborating upon and effectively enforcing the principles and general regulations adopted on the global level.

REFERENCES

BLOCK, R. H. and G. R. HELZ (editors) 1977. Proceedings of the chlorination workshop, 1977. Chesapeake Science, 18.

B.P., 1979. B.P. statistical review of the world oil industry, 1979. The British Petroleum Company Ltd., London, 32 pp.

BURTON, J. D. and P. S. LISS (editors), 1977. Estuarine Chemistry. Academic Press, N.Y.

CUSHING, D. H., in press. Sources of variability in the North Sea ecosystem. Presented at the Proceedings of the Symposium on North Sea Dynamics, Hamburg 1981. Springer Verlag.

DAVIES, J. M. and J. GAMBLE, 1979. Experiments with large enclosed ecosystems. Philos.Trans.R.Soc.Lond.B.Biol.Sci., 286, 523-544.

FAO, 1981a. Review of the state of world fishery resources. Marine Resources Service, Fishery Resources and Environment Division, Fisheries Department, Fisheries Circular No. 710, rev. 2, FAO, Rome, 52 pp.

FAO, 1981b. Yearbook of fishery statistics - catches and landings, 1979. Vol. 50, FAO, Rome.

GESAMP, 1975. Reports and Studies No. 3: The scientific criteria for the selection of sites for dumping of wastes into the sea.

GESAMP, 1977a. Reports and Studies No. 6: Impact of oil in the marine environment.

GESAMP, 1977b. Reports and Studies No. 7: Scientific aspects of pollution arising from the exploration and exploitation of the sea-bed.

GESAMP, 1980a. Reports and Studies No. 11: Marine pollution implications of coastal area development.

GESAMP, 1980b. Reports and Studies No. 12: Monitoring biological variables related to marine pollution.

GESAMP, 1980c. Reports and Studies No. 13: Interchange of pollutants between the atmosphere and the oceans.

GOLDBERG, E. D. (1976). The Health of the Oceans. UNESCO, Paris.

GOLDBERG, E. D. (editor), 1979. Assimilative Capacity of U.S. Coastal Waters for Pollutants. U.S. Department of Commerce, NOAA Environmental Research Laboratories, 284 pp.

GROSS, M. G., 1976. Middle Atlantic Continental Shelf and the New York Bight. Am.Soc.Limnol.Oceanogr. Spec.Symp.2 : 441 pp.

IAEA, 1976. Effects of ionizing radiation on aquatic organisms and ecosystems. Tech.Rep.Ser. 172, IAEA, Vienna, 131 pp.

French, C.O., 1981. Gulf of Mexico: A Socioeconomic View of Competing Resources. Proceedings of a Symposium on Environmental Research Needs in the Gulf of Mexico (GOMEX), Key Biscayne, Florida. Vol. IIA. NOAA, Miami. U.S.A.

IAMAP, 1981. International Commission on Atmospheric Chemistry and Global Pollution: Abstracts p.36, Hamburg meeting 1981.

ICES, 1977a. Petroleum hydrocarbons in the marine environment. Rapp.P.-V.Réun. Cons.Int.Explor.Mer., 171.

ICES, 1977b. The ICES Co-ordinated monitoring programme in the North Sea, 1974. Coop.Res.Rep., 58, ICES, Copenhagen, 19 pp.

ICES, 1977c. Studies of the pollution of the Baltic Sea. Coop.Res.Rep. 63, ICES, Copenhagen, 97 pp.

ICES, 1980a. Biological effects of marine pollution and the problems of monitoring. Rapp.P.-V.Réun.Cons.Int.Explor.Mer., 179.

ICES, 1980b. A review of the past and present measurements of selected trace metals in sea water in the Oslo Commission and ICNAF/NAFO areas. Coop.Res.Rep.97, ICES, Copenhagen, 43 pp.

ICES, 1981. An overview of mercury in the marine environment. Annex 2 in: Report of the ICES Advisory Committee on Marine Pollution, 1980. Coop.Res.Rep. 103, ICES, Copenhagen, 24 pp.

ICES, 1982. Report of the Advisory Committee on Marine Pollution, 1981. Coop.Res.Rep., 112, ICES, Copenhagen, 67 pp.

IOC, 1976. A comprehensive plan for the global investigation of pollution in the marine environment. IOC Tech.Ser.14. UNESCO.

IOC, (in preparation). Technical Supplement to "The Health of the Oceans". IOC Technical Series No. 23.

IZRAEL, Y. A. and A. V. TSYBAN, 1981. Problems of monitoring the ecological consequences of ocean pollution. J.Oceanogr.Soc. Japan, 36(6), 293-314.

JENNE, E. A. (editor), 1979. Chemical modelling in aqueous systems. Am.Chem.Soc., Washington, D.C.

KINEMAN, J. J., R. ELMGREN and S. HANSSON (editors), 1980. The TSESIS Oil Spill. NOAA, US Dept. of Commerce, 296 pp.

KUREISHY, T. W., M. O. GEORGE and R. SEN GUPTA, 1978. DDT contamination in zooplankton from the Arabian Sea. Indian J.Mar.Sci., 7, 54-55.

MELVASALO, T., J. PAWLAK, K. GRASSHOFF, L. THORELL and A. TSYBAN (editors), 1981. Assessment of the effects of pollution on the natural resources of the Baltic Sea. Baltic Sea Environment Proceedings No. 5A and 5B.

NAS, 1978. The Tropospheric Transport of Pollutants and other Substances to the Oceans. U.S. National Academy of Sciences, Washington, D.C. pp. 124-245.

NAS/NRC, 1978. An assessment of mercury in the environment. National Academy of Sciences, National Research Council, Washington, D.C.

NIO, 1976. Report on the marine environment monitoring and marine living assessment programme for the Indian Ocean Region. Phase I - Survey of institutional capabilities (Report submitted to UNEP - Nov. 1976).

NRC, 1974. Report of the Panel on the Sea-to-Air Transfer of Materials in the Sea, of the U.S. National Research Council's Dumping Workshop held in Woods Hole, Massachusetts, 9-13 September 1974.

OECD, 1980. Chemical trends in wildlife: An international co-operative study, 248 p. OECD sales no. 700 DH 97 80 06 1.

OSTLUND, H. G., H. G. DORSEY, and R. BRESCHER, 1976. GEOSECS Atlantic radiocarbon and tritium results (Miami). Tritium Laboratory Data Report No. 5, Rosenthal School of Marine and Atmospheric Sciences, University of Miami.

PRESTON, A., 1979. Standards and environmental criteria: The practical application of the results of laboratory experiments and field trials to pollution control. Philos.Trans.R.Soc.Lond.B.Biol.Sci., 286, 611-624.

SCOPE, 1976. Nitrogen, phosphorus and sulphur: global cycles. SCOPE Report 7, John Wiley & Sons, New York, 192 pp.

SCOPE, 1977. Environmental issues. SCOPE Report 10, John Wiley & Sons, New York, 224 pp.

SCOPE, 1979. The global carbon cycle. SCOPE Report 13, John Wiley & Sons, New York, 491 pp.

STEELE, J. H., 1974. The Structure of Marine Ecosystems. Harvard University Press, Cambridge, Mass. 128 pp.

STUMM, J. H. (editor), 1977. Global Chemical Cycles and their Alterations by Man. Dahlem Konferenzen, Physical and Chemical Sciences Research Report 2, Berlin, 347pp.

SUNAY, M. T. I. BALKAS, I. SALIHOGLU and G. RAMELOW, 1979. Determination and distribution of organochlorine residues and heavy metals in tar balls. IVes Journées d'études sur les pollutions marines en Mediterranée; ICSEM/UNEP.

SWANSON, R. L. and C. J. SINDERMANN (editors) 1979. Oxygen depletion and associated benthic mortalities in New York Bight, 1976. NOAA Professional Paper 11. US Dept. of Commerce.

UNESCO, 1979. The mangrove ecosystem: human uses and management implications. UNESCO reports on the marine environment, 8.

UNESCO, 1981. River inputs to ocean systems (R.I.O.S.), Proceedings of a Workshop, Rome, March 1979. United Nations, New York.

WHO, 1976. Polychlorinated biphenyls and terphenyls. Environmental Health Criteria 2: 85 pp. WHO, Geneva.

WOOD, J. M. and E. D. GOLDBERG, 1977. Impact of metals on the biosphere. In Stumm, W. (editor): Global Chemical Cycles and their Alterations by Man. Dahlem Konferenzen, Physical and Chemical Sciences Research Report 2, Berlin, 347 pp.

GLOSSARY

This list provides guidance on a selection of technical terms and on some everyday words which are used in a specialized sense in the report.

ADIPOSE TISSUE   A type of connective tissue specialized for storage of fat

ADSORPTION   The surface retention of solid, liquid, or gas molecules, atoms or ions by a solid or liquid as opposed to absorption, the penetration of substances into the bulk of the solid or liquid

AEROSOL   A gaseous suspension of ultramicroscopic particles of a liquid or a solid

ANOXIC   Devoid of free oxygen

ANTHROPOGENIC   Man-made

AUTHIGENIC   Formed by sedimentary processes as a crystallographic unit at the
(of a mineral)   place of its occurrence

BENTHIC   Of, pertaining to, or living on or in the bottom of the sea

BIOGENIC   Produced by the action of living organisms

BIOTURBATION   Disturbance of sediments by the activities of living organisms

CHELATE   A molecular structure in which a heterocyclic ring can be formed by the unshared electrons of neighbouring atoms

COMPLEXATION   Formation of a chemical compound in which part of the molecular bonding is of the co-ordinate type

CORIOLIS EFFECT   The deflection relative to the earth's surface of any object moving above the earth, caused by the Coriolis force; an object moving horizontally is deflected to the right in the northern hemisphere, to the left in the southern

DEPURATE   Become free from contaminants

DESORPTION   The process of removing a sorbed substance by the reverse of adsorption or absorption

DETRITUS   Strictly speaking, loose particles produced by wearing away of larger material but the term is often used more generally to refer to fine inorganic or organic matter suspended in the water or settled on the sea bed

DIAGENESIS   Physical and chemical changes occurring in sediments during and after their deposition but before their consolidation

DIVALENT (metal)   One whose atoms are each capable of combining with two atoms of hydrogen

ENTRAIN   Carry along in the flow (of water)

EUPHOTIC ZONE   The upper level of the sea down to the limits of effective light penetration for photosynthesis

EUTROPHICATION   The process of nutrient enrichment of water which leads to enhanced organic growth but which if carried too far (hyper-trophication) causes undesirable effects

FLUSHING TIME   For sea areas, this usually refers to the time taken for the volume of water in a designated location to be replaced by water from outside; a concept which engenders high-energy discussions between physical oceanographers and engineers

GRADIENT   The rate of change of a property with respect to distance (horizontal or vertical)

HOMOLOGUE (chemical)   One of the compounds in a series which shows graded changes in structure and properties

HYDROXYLATION (chemical)   An oxidation reaction which introduces one or more hydroxyl groups into an organic compound

ISOMER   One of two or more chemical substances having the same elementary percentage composition and molecular weight, but differing in structure and therefore in properties

LIGAND   The molecule, ion, or group bound to the central atom in a chelate or a co-ordination compound

PORE WATER   Water filling the small openings and channels within rocks or sediments

PYCNOCLINE   A density gradient - see thermocline

SCAVENGING   Removing a solid, liquid or gas from a liquid or gas by its adherence to a third substance

SPECIATION (of a chemical)   Refers to the various forms in which a chemical can exist

TECTONIC   Said of rock structures which are directly attributable to earth movements involved in folding and faulting

THERMOCLINE   A temperature gradient, as in a layer of sea-water, in which the temperature decrease with depth is greater than that of the overlying and/or underlying water

UPWELLING   The process by which water rises from a deeper to a shallower depth, usually as a result of divergence of offshore currents

CONTENTS OF THE TECHNICAL SUPPLEMENT

The papers listed below were prepared for and used by the Working Group. They will, subject to the authors' approval, be reproduced in the volume published by UNESCO, as No. 23 in the IOC Technical Series.

Part III - Pollutants in the marine environment

1. A. D. McIntyre: Sewage

2. H. I. Shuval: The disappearance of bacteria and viruses in sea-water

3a. M. de Barros, D. Elder and G. R. Harvey: Organochlorines

3b. A. V. Holden: The analysis of marine samples for organochlorines

4. E. M. Levy: Oil on the surface of the oceans

5. E. M. Levy: Effects of oil pollution on stressed marine organisms

6. P. G. Jeffery: Impact of oil on the marine environment

7. P. Jeffery and A. Jernelov: Biological impact on and recovery of ecosystems
    affected by oil spills

8. M. Bernhard: Trace metals

9. W. Templeton and A. Preston: Management of ocean disposal of radioactive
    wastes

10. L. Magos: Toxicological principles

11. B. T. Hargrave and H. Thiel: Benthic community structure

Part IV - Specific problems of regional significance

1. M. Bernhard: Mediterranean Sea

2. S. Garzoli: South-West Atlantic

3. A. Gilmour: Australia

4. K. Hunter: Marine pollution in the New Zealand waters

5. G. Kullenberg: The Baltic Sea: a brief presentation and discussion of its
    pollution problems

6. A. D. McIntyre: The health of the North Sea

7. B. J. Presley: Man's influence on the chemistry of the Gulf of Mexico

8. R. Sen Gupta: Environmental problems in the Indian Ocean region

9. E. Tutuwan: Summary of studies on marine pollution in the Gulf of Guinea and
    its adjacent areas

10. F. Valdez-Zamudio: Brief summary on marine pollution in the South-East Pacific

11. M. Waldichuk: Brief review of marine pollution in coastal waters of North
    America

12. IOC: International control of marine pollution

ACKNOWLEDGEMENTS

Professor Gunnar Kullenberg
Chairman of the Working Group

Geneva, 16 April 1982

MEMBERS AND CORRESPONDING MEMBERS
OF THE WORKING GROUP

Prof. G. Kullenberg
Institute of Physical Oceanography
University of Copenhagen
Haraldsgade 6
2200 Copenhagen
Denmark

Dr. R. Ali
Fisheries Adviser
Ministry of Agriculture and
  Fisheries
P.O. Box 1509
Dubai
United Arab Emirates

Dr. T. I. Balkas
Middle East Technical University
Marine Science Department
P.K. Erdemli Içel
Turkey

Dr. M. de Barros
Direcção-General de Protecção da
Produção Agricola
Quinta do Marques
2780 Oeiras
Portugal

Dr. K. Beijer
Swedish Water and Air Pollution
  Research Laboratory
Drottig Kristinas Vag 47
11428 Stockholm
Sweden

Dr. M. Bernhard
Environmental Protection Research
  Division
Laboratorio per lo Studio della
  Contaminazione Radioattiva del Mare
19030 Fiascherino (La Spezia)
Italy

Dr. N. L. Bienati
Avda Quintana 282
- 2 piso Depto G
1014 Capital Federal
Buenos Aires
Argentina

Dr. B. P. Boudreau
Texas A & M University
College Station
Tx. 77843
United States of America

Dr. V. T. Bowen
Department of Chemistry
Woods Hole Oceanographic Institute
Woods Hole, Mass. 02543
United States of America

Prof. R. Chesselet
Centre des Faibles Radioactivités
Laboratoire Mixte CNRS/CEA
B.P. No. 1
91190 Gif sur Yvette
France

Mr. H. D. Dooley
Department of Agriculture and
  Fisheries for Scotland
Marine Laboratory
P.O. Box 101
Victoria Road
Aberdeen AB9 8DB
United Kingdom

Dr. E. Duursma
Delta Institute for Hydrobiological
  Research
Vierstraad 28
4401 EA Yerseke (Zeeland)
Netherlands

Dr. D. L. Elder
United Nations Environment Programme
Palais des Nations
CH 1211
Geneva 10
Switzerland

Dr. K. A. Fanning
University of South Florida
Department of Marine Science
St. Petersburg
Florida 33701
United States of America

Dr. S. Fowler
International Laboratory of Marine
   Radioactivity
Musée Océanographique
Monaco
Principauté de Monaco

Dr. W. Garrett
Ocean Sciences Division
Naval Research Laboratory
Code 8330
Washington DC, 20 375
United States of America

Ms. S. Garzoli
Lamont-Doherty Geological Observatory
   of Columbia University
Palisades N.Y. 10964
New York
United States of America

Dr. A. Gilmour
GBRMPA
P.O. Box 1379
Townsville
Queensland 4810
Australia

Dr. R. Hargrave
Bedford Institute of Oceanography
Atlantic Oceanographic Laboratory
P.O. Box 1006
Dartmouth
Nova Scotia B2Y 4A2
Canada

Dr. G. Harvey
Ocean Chemistry Laboratory
Department of Commerce (NOAA/AOML)
15 Rickenbacker Causeway
Miami, Florida 33149
United States of America

Dr. A. V. Holden
Freshwater Fisheries Laboratory
Faskally
Pitlochry PH16 5LB
Perthshire
Scotland

Dr. K. Hunter
University of Otago
Chemistry Department
Box 56
Duneden
New Zealand

Dr. Y. A. Izrael
Hydrometeorological Service of the USSR
12 Pavlik Morozov Pereulok
Moscow D-376
USSR

Dr. P. G. Jeffery
Warren Spring Laboratory
Gunnels Wood Road
Stevenage
Herts.
United Kingdom

Dr. A. Jernelöv
Swedish Water and Air Pollution
   Research Laboratory
Drottig Kristinas Vag 47
11428 Stockholm
Sweden

Dr. R. Johnston
Department of Agriculture and Fisheries
   for Scotland
Marine Laboratory
P.O. Box 101
Victoria Road
Aberdeen AB9 8DB
United Kingdom

Dr. F. I. Khalaf
Environmental Department
Kuwait Institute for Scientific Research
P. O. Box 12009
Kuwait

Prof. Z. Kowalik
Institute of Meteorology and
   Water Management
Maritime Branch
ul. Waszyngtona 42
81-342 Gdynia
Poland

Prof. D. Lal
Physical Research Laboratory
Navrangpura
Ahmedabad 38 0009
India

Dr. E. M. Levy
Bedford Institute of Oceanography
Atlantic Oceanographic Laboratory
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

Dr. L. Magos
MRC Toxicology Unit
Medical Research Council
   Laboratories
Woodmansterne Road
Carshalton
Surrey SM5 4EP
United Kingdom

Dr. J. M. Martin
Laboratoire de Géologie
Ecole Normale Supérieure
46 rue d'Ulm
75230 Paris Cedex 05
France

Dr. A. D. McIntyre
Department of Agriculture and
   Fisheries for Scotland
Marine Laboratory
P.O. Box 101
Victoria Road
Aberdeen AB9 8DB
United Kingdom

Dr. G. Needler
Bedford Institute of Oceanography
Atlantic Oceanographic Laboratory
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

Dr. B. J. Presley
Texas A & M University
College Station
Tx. 77843
United States of America

Prof. G. G. Polikarpov
Institute of Biology of Southern Seas
Prospect Nachimova 3
Sebastopol
U.S.S.R.

Dr. J. Portmann
Ministry of Agriculture, Fisheries
   and Food
Fisheries Laboratory
Remembrance Avenue
Burnham on Crouch
Essex CMO 8HA
United Kingdom

Dr. V. Pravdić
Centre for Marine Research
"Rudjer Bosković" Institute
P.O.Box 1016
41001 Zagreb
Yugoslavia

Mr. A. Preston
Ministry of Agriculture, Fisheries
  and Food
Fisheries Laboratory
Lowestoft
Suffolk NR33 OHT
United Kingdom

Dr. L. Saliba
Department of Biology
Old University
Msida
Malta

Dr. D. Schink
Department of Oceanography
Texas, A and M University
College Station
Texas 77843
United States of America

Dr. R. Sen Gupta
National Institute of Oceanography
Dona Paula - 403004
Goa
India

Dr. A. Soegiarto
National Institute of Oceanology
Indonesian Institute of Sciences
Jalorn Aquarium
Sundor Kelapa
P.O. Box 580/DAK
Jakarta
Indonesia

Prof. H. I. Shuval
The Hebrew University
Hadassah Medical School
Environmental Health Laboratory
Jerusalem
Israel

Dr. W. Templeton
Batelle Pacific
Northwest Laboratories
P.O. Box 999
Richland, Va. 99352
United States of America

Dr. H. Thiel
Universitaet Hamburg
Institut für Hydrobiologie
  und Fischereiwissenschaft
Koenigstrasse
2000 Hamburg 50
F.R. of Germany

Dr. A. Tsyban
Department for Marine Biological
  Monitoring
State Oceanographic Institute
6 Kropotkinsky Pereulok
Moscow G-34
USSR 119034

Dr. E. Tutuwan
Department of Organic Chemistry
Faculty of Science
University of Cameroon
P.O. Box 1816
Yaounde
Cameroon

Mr. F. Valdez-Zamudio
Coronel Inclán 806
Miraflores
Lima 18
Perú

Dr. M. Waldichuk
West Vancouver Laboratory
Department of Fisheries and Oceans
4160 Marine Drive
West Vancouver B.C., V7V 1N6
Canada

Dr. M. Whitfield
Marine Biological Association of the U.K.
Citadel Hill
Plymouth
Devon
United Kingdom