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The state of the marine environment

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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 IOC retain a consultant to bring together the available data into a report on the Health of the Oceans. Professor E. D. Goldberg was asked to do this work, and his report was published by UNESCO in 1976.[1]

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 up 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.[2]

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

2 The Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) is an advisory body to the Heads of eight organizations of the United Nations System (UN, UNEP, FAO, Unesco, WHO, WMO, IMO, and IAEA).

LIST OF ABBREVIATIONS

CCCO	Committee on Climate Change and the Ocean
CFC	Chlorofluorocarbons
DDE	1, 1 - dichloro - 2, 2 - bis (p-chlorophenyl) ethylene
DDT	1, 1, 1 - trichloro - 2, 2 - bis (p-chlorophenyl) ethylene
DSP	Diarrhoeic shellfish poisoning
EC	Environmental capacity
EQO	Environmental quality objective
FAO	Food and Agriculture Organization
GEEP	Group of Experts on Environmental Pollutants
GESAMP	Group of Experts on the Scientific Aspects of Marine Pollution
grt	Gross registered tons
Gt	Gigatonne
HCB	Hexachlorobenzene
HCH	Hexachlorohexane
IAEA	International Atomic Energy Agency
ICES	International Council for the Exploration of the Seas
ICRP	International Commission for Radiological Protection
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
IOC	International Oceanographic Commission
JGOFS	Joint Global Ocean Flux Study
LDC	London Dumping Convention
MARPOL	International Convention for the Prevention of Pollution from Ships
mSv	Millisievert
Mt	Megatonne
OILPOL	International Convention for the Prevention of Pollution of the Sea by Oil
OTEC	Ocean thermal energy conversion
PAH	Polyaromatic hydrocarbons
PBq	Petabecquerel
PCB	Polychlorinated biphenyls
ppb	parts per billion
ppm	parts per million
PSB	Paralytic shellfish poisoning
TBT	Tributyltin
TOGA	Tropical Ocean and Global Atmosphere Programme
UES	Uniform emission standard
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNSCEAR	United Nations Committee on the Effects of Atomic Radiation
UV	Ultraviolet
WCRP	World Climate Research Programme
WHO	World Health Organization
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

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EXECUTIVE SUMMARY

1. In 1989 man's fingerprint is found everywhere in the oceans. Chemical contamination and litter can be observed from the poles to the tropics and from beaches to abyssal depths. But conditions in the marine environment vary widely.

2. The open sea is still relatively clean. Low levels of lead, synthetic organic compounds and artificial radionuclides, though widely detectable, are biologically insignificant. Oil slicks and litter are common along sea lanes, but are, at present, of minor consequence to communities of organisms living in open-ocean waters.

3. In contrast to the open ocean, the margins of the sea are affected by man almost everywhere, and encroachment on coastal areas continues worldwide. Habitats are being lost irretrievably to the construction of harbours and industrial installations, to the development of tourist facilities and mariculture, and to the growth of settlements and cities. Although difficult to quantify, destruction of beaches, coral reefs and wetlands, including mangrove forests, as well as increasing erosion of the shore, are evident all over the world. If unchecked, this trend will lead to global deterioration in the quality and productivity of the marine environment.

4. The growing exploitation of the coast is a reflection of population increase, accelerating urbanization, greater affluence and faster transport - trends that will continue throughout the world. Controlling coastal development and protecting habitats will require changes in planning both inland and on the coast, often involving painful social and political choices.

5. A wide range of activities on land contributes to the release of contaminants to the sea either directly or carried by rivers and the atmosphere, while sea-borne activities make a minor addition. Only a small part of those contaminants has spread beyond the limits of the continental shelf. The bulk remains in coastal waters and, in places, particularly in poorly flushed areas, has built up to significant levels. Our views on these contaminants are summarized below in what is judged as their current order of importance.

6. The rate of introduction of nutrients, chiefly nitrates but sometimes also phosphates, is increasing, and areas of eutrophication are expanding, along with enhanced frequency and scale of unusual plankton blooms and excessive seaweed growth. The two major sources of nutrients to coastal waters are sewage disposal and agricultural run-off from fertilizer-treated fields and from intensive stock raising. The degree of damage varies from area to area, reflecting site conditions and nutrient load. Nutrient contamination is costly in terms of lost resources and spoiled amenity but effective remedial action is difficult. It will involve large investments in treatment plants and in sludge and effluent disposal, and major changes in agricultural practices. It is also difficult to relate these inputs to the occurrence of blooms because the quantitative relations between nutrient input and eutrophication are unclear and because of the confounding role of other ecological factors and of climatic variations.

7. Microbial contamination from sewage causes many human diseases, including cholera and hepatitis A. Control requires proper design and siting of outfalls, coupled with rigorous surveillance of shellfish beds and their marketed products, and the timely banning of contaminated seafood. Microbial contamination of sea water

unfit for human consumption. However, coastal nursery grounds and shallow waters are being increasingly degraded, and marine resources, both wild and farmed, could eventually be damaged on a global scale. In addition, the exploitation of living marine resources may degrade the environment by damaging habitats and altering food webs, while mariculture, which is rapidly expanding, generates its own local pollution and may upset the ecological balance by the introduction of exotic species and diseases.

15. These are problems on which action can be identified now. There are additional issues that cannot at present be fully assessed in relation to the seas, namely, the effects of climate change, including a possible rise in sea level resulting from global warming due to increases in greenhouse gases, and the impact of a reduction of stratospheric ozone, which may affect marine resources through increased exposure to ultraviolet radiation.

16. A number of international agreements now supplement national regulations aimed at protecting the seas. They concern mainly pollution from sea-borne sources and have played a role in reducing ocean pollution, particularly by oil residues. However, much remains to be done to control land-based sources, the main contributors to contamination of the sea.

17. We conclude that, at the end of the 1980s, the major causes of immediate concern in the marine environment on a global basis are coastal development and the attendant destruction of habitats, eutrophication, microbial contamination of seafood and beaches, fouling of the seas by plastic litter, progressive build-up of chlorinated hydrocarbons, especially in the tropics and the subtropics, and accumulation of tar on beaches. However, concerns may differ from region to region, reflecting local situations and priorities. Furthermore, throughout the world, public perception may still accord greater importance to other contaminants such as radionuclides, trace elements and oil. These were highlighted in the 1982 GESAMP Review and are considered again in the present report, but we now regard them as being of lesser concern.

18. While no areas of the ocean and none of its principal resources appear to be irrevocably damaged, and most are still unpolluted, while there are encouraging signs that in some areas marine contamination is decreasing, we are concerned that too little is being done to correct or anticipate situations that call for action, that not enough consideration is being given to the consequences for the oceans of coastal development, and that activities on land continue with little regard to their effects in coastal waters. We fear, especially in view of the continuing growth of human populations, that the marine environment could deteriorate significantly in the next decade unless strong, co-ordinated national and international action is taken now. At the national level in particular, the concerted application of measures to reduce wastes and to conserve raw materials will be essential. The efforts will be great and the costs high, but nothing less will ensure the continued health of the sea and the maintenance of its resources.

5. The biological impact of man's activities is considered, particularly the effects of wastewater discharges on human health, and the changes of inshore ecosystems caused by nutrient inputs. The increasing loss of natural coastal habitats around the world is documented, with special reference to wetlands such as mangrove forests, to seagrass beds and to the very sensitive coral ecosystems. Longer-term problems include the possibility of subtle effects of persistent low levels of contamination, as well as the effects of an increased ultraviolet flux due to depletion of the stratospheric ozone layer, and the consequences of increases in the "greenhouse" gases which are expected to produce a rise in sea level and a change in climate patterns with unknown effects on marine ecosystems.

6. The increasing world population, its preferential settlement in the coastal zone and the resulting industrialization of that area will only exacerbate the problems at the margins of the seas, in contrast to the open oceans. These problems arise at a time of increasing environmental awareness, and it is important that a broad and balanced view be taken of how best to protect the environment. The essential linkage between terrestrial, aquatic and marine compartments should be recognized, and all available options considered.

7. At the same time it is important to distinguish between perceived and real problems, recognizing that the assessment of an issue by the scientific community may differ from that of the general public. While public perceptions, however insubstantial, must be taken seriously, and while it is entirely proper that political action should take account of them, efforts should be made to provide rational explanations and ensure that the public is well informed about the state of the current knowledge. It should also be recognized that what is possible and indeed mandatory for an industrialized country may need to be viewed in a different light in the developing world.

8. Against this background, the report considers the existing mechanisms for protecting the marine environment and controlling pollution. It refers to their national and international aspects and concludes with an overview of the most important problems facing the seas.

9. Almost ten years have now passed since GESAMP presented its first report on the Health of the Oceans. It is relevant to note briefly some of the changes that have taken place in that decade. Analytical techniques have been improved, satellite observations have come into use for large scale studies, techniques for process control and pollution abatement have been further developed, new national legislation and regulations have been introduced, and international agreements reached on a wide range of environmental issues. Significant changes have occurred in the pattern of energy use, with associated reductions in the amount of oil transported at sea. Finally, there have been some major accidents involving shipping, the chemical industry and nuclear installations. The scientific literature on marine pollution has increased by at least 50 per cent. A greater degree of public interest and sensitivity to the environment has developed, raising expectations and causing changes in priorities for action. These are reflected in the discussions that follow.

I. HUMAN ACTIVITIES AFFECTING THE SEA

12. In discussing the state of the oceans it is appropriate to focus on those human activities that are likely to affect the marine environment. This chapter examines the most important of them. For some the impact is a matter of immediate concern, particularly where human health is involved, and prompt action is required. For others, there will be consequences only in the medium or long term, but it is none the less important to recognize problems as early as possible so that effective measures can be initiated before damage occurs.

A. DEVELOPMENT OF COASTAL AREAS

13. The coastline is a complex region comprising bays, estuaries, and large semi-enclosed areas where human populations and industrial development are concentrated. It is the focus for contaminants from inland areas as well as from developments along its length. Most of the sources of contamination discussed in this chapter contribute directly or indirectly to problems in the immediate coastal zone, and arise from activities specifically located there.

14. Although a relationship between human population increase and environmental change has long been recognized, attempts have been made only recently to assess the cumulative impacts of land development in the coastal zone by recording their physical, chemical and biological consequences. This requires knowledge of trends in water quality, and an understanding of the management of aquatic habitats. Equally important is the economic analysis of damage to natural resources and human health against which the cost of control measures will need to be justified. Many of the impacts recorded are common to most coastal developments, but it is useful to consider industrial and recreational activities separately.

15. The development and maintenance of ports and harbours is of prime concern to human populations. Water exchange in these areas is often limited and shipping activities introduce contaminants, including oily wastes, cargo escapement and human wastes released from shipboard. These are subject to national and international regulations, but contamination at ports is difficult to control since it enters the sea by many routes, including discharges from pipes, run-off from streets, roofs and parking areas, and inputs from the atmosphere. Also, harbours are the first point of contact with the sea for many rivers, which add a wide variety and large quantity of land-derived material.

areas, but awareness, resources and political will are needed if the health of the resident and the transient populations, the survival of marine wildlife and the functional integrity of the vital land-sea interface are to be maintained.

B. DISCHARGE OF WASTEWATERS

22. Contaminants from land reach the marine environment by a variety of pathways. Coastal outfalls discharge directly to estuaries, inshore waters, bays and open coastal areas. Storm-water flows may be too great for drainage and treatment facilities and, when run-off is too fast, may exceed the assimilative capacity of the receiving waters. Rivers act as large-scale collectors and carriers of wastewaters from diverse sources within their drainage basins and offload them to the sea. Thus, rivers can be regarded as major point sources of mixed contaminants, the inputs of which depend on the contaminant load of the rivers and on the physico-chemical and biological transformations taking place in the river itself, and especially in the estuaries and the near-shore zone.

23. Non-point sources draining to coastal waters include surface run-off from agricultural areas, wash-out of agrochemicals, and transport of sediment due to coastal erosion or to deforestation and desertification in the hinterland. Land management practices largely determine these various influxes.

24. River inputs and non-point sources are discussed elsewhere (section II A). This chapter focuses on direct discharges from point sources along the coastline. Two are predominant: domestic sewage and industrial effluents. In urban areas both waste streams are often mixed in sewerage systems and reach the sea together as municipal wastewater. This then contains material of domestic origin as well as a variety of industrial and other effluents with higher concentrations of contaminants which have been discharged to the community sewerage systems.

25. Contaminants from these sources can be grouped as follows:

- micro-organisms
- organic material affecting oxygen balance
- nutrients
- trace elements
- synthetic organic compounds
- petroleum-related compounds
- particulates/sediments
- heat

It should be emphasized that effluents usually contain a mixture of these, the composition varying

ing of chemical pollution.

31. In the past, most pollution control strategies had been prompted, usually *post hoc*, by evident effects of, for example, excessive oxygen demand, or of discharges of nutrients, metals and pathogenic organisms, but recent and current policies try to forestall effects by controlling inputs, defining potentially hazardous substances and stringently limiting their disposal. However, toxicological information by itself cannot be the basis of control. Knowledge of discharge loading and dilution rates, as well as evidence of effects on specific organisms, is required.

32. Few municipal wastewater treatment plants handle domestic sewage alone; most have an industrially contributed load in addition, restricting the options for efficient waste treatment and sludge utilization. The degree of contaminant removal and the nature of the effluent discharge depend upon the types of substances released from industry, the treatment process technology used, the design of the treatment plant, and its operational efficiency. Most of the large urban/industrial centres in developing countries have no effective wastewater treatment system, and the siting and design of their outfalls often do not provide adequate dilution and dispersion, thus potentially endangering human health and resources.

33. Even in developed countries, large population centres are still likely sources of contaminants through their untreated domestic effluents. Thus, while Marseilles, France, has very recently set up a modern sewage treatment plant, a number of large cities on the industrialized northern shore of the Mediterranean and its hinterland still lack one. Even when facilities are available, they may be inadequate when load is high owing to seasonal increases. In these cases additional treatment for peak load capacity can be costly to provide, and overflow release may be preferred in the short term, but appropriately sited offshore outfalls are needed, and these require surveillance to ensure that they are, and continue to be, effective.

34. In tropical and sub-tropical oceanic areas where long stretches of the coast may be rather sparsely populated, most of the sewage from small communities either does not reach the sea or is too diluted on discharge to cause detectable harm. Notable exceptions are population centres in coastal areas and estuaries in Latin/Central America, South-East Asia and Western Africa and some small but densely populated oceanic islands. During storms, domestic and industrial wastewaters from large metropolitan areas often reach the sea through storm-water overflow and open canals, receiving no treatment. Seafood harvested in these places constitutes one of the major public health hazards related to the marine environment.

sea disposal is concentrated at a single site or repeated as a cyclic operation over a more extensive area. Cycling will be more damaging if the capacity or time scale for recovery or recolonization of a slow-growing community is exceeded by too frequent discharges.

40. Mine tailings are of particular concern. It has been a common practice at coastal mines to dispose of waste materials to the sea either directly or by dumping into rivers from where the wastes are periodically swept to the sea during flooding. Some effluents are chemically inert, for example from china-clay mining, and the environmental effect is largely due to physical blanketing. For metal ore mining, on the other hand, operations extend from initial extraction-concentration activities to the final smelting-refining procedures. The resulting wastes are toxic, particularly those from the later stages, since the refined product often comes from intensive chemical treatment designed to isolate metals and their compounds. The main metal products from coastal mines and/or processing facilities are aluminium, copper, iron, lead, mercury, molybdenum, tin, and zinc.

2. *Industrial wastes and sewage sludge*

41. Industrial wastes dumped at sea can present much more varied and intractable problems. They may be highly acidic or alkaline; liquid or largely particulate, and anything from relatively inert to extremely toxic. They include wastes from the chemical, petrochemical and pharmaceutical industries, from pulp and paper production, from smelters, from the food industry, from flue-gas washings and from military activities. Pre-treatment of wastes at industrial sites before disposal is judged to be essential in an increasing number of countries. LDC records show that in the period 1970-1985 the largest amount of industrial waste dumped at sea was 17 million tonnes in 1982, and the smallest, 6 million tonnes in 1984.

42. The monitoring techniques used in assessing the impact of waste disposal to the sea involve physical or chemical tests and species-diversity studies, but some are procedurally complex and costly, and all are difficult to interpret if not properly planned and carried out. Many of the data are not comparable between sites or studies because of the specificity of discharges, disposal sites and targets, and because standard procedures are not routinely used. Earlier studies are not always of direct practical use in environmental forecasting for new developments. Current monitoring strategies and practices in relation to the disposal of industrial wastes at sea should be reviewed to assess their effectiveness. Guidelines should be developed to ensure that all relevant variables and only the relevant ones are monitored.

43. The sludge arising from the treatment of sewage can be used as fertilizer on agricultural land or for land reclamation, when it is not contaminated with high levels of metals, oils and organic chemicals. However, in some cases it may be more economic and environmentally preferable to dispose of it at sea. Municipal sewage sludge normally does not contain contaminants in high concentrations, but excessive dumping may have harmful effects such as oxygen depletion and

48. On available evidence, the environmental implications of incineration at sea cannot be regarded as more significant than those of incineration on land. There are limitations and risks associated with either choice. In practice, the choice will depend on a careful analysis of technical, social, and political as well as environmental factors. Pending the outcome of the 1992 LDC assessment, some countries, for instance small island countries, may find incineration at sea to be the preferred, or even the only, option for the disposal of certain wastes. For these reasons, GESAMP considers it appropriate to review the environmental aspects of this technology at an early date.

D. DISPOSAL OF PLASTIC LITTER

49. The sea is inevitably the recipient of solid matter, intentionally disposed of or accidentally lost. This can interfere with fishing, shipping and other marine activities, but can also support life in the sea by providing additional surfaces for encrusting organisms and shelter for mobile species. In the past, much of such solid matter disintegrated quickly, but resistant synthetic substances have been replacing many natural, more degradable, materials and this trend is continuing.

50. There is now growing concern among fishermen, scientists, seafarers, conservationists, and tourists about the increasing amounts of plastic material found at sea and on beaches. Such litter originates from both land-based and sea-borne sources. Most beaches near population centres are littered by a multitude of plastic residues washed up from the sea, contributed by rivers, ships and outfalls, dumped by illegal refuse operators, or left behind by beach users.

51. Since most synthetic materials are buoyant and persistent, they present a threat to living organisms and the natural environment. Plastic debris can be loosely classified in three groups: (1) fishing gear and equipment, such as nets and lines; (2) packing bands, straps and synthetic ropes; and (3) plastic litter, including bags, bottles, sheeting, packaging material and small pellets from which "user" plastics are manufactured. Such debris has been recorded, sometimes in large quantities, in the oceans, including the polar regions, and from intertidal areas to abyssal depths.

52. First, debris from fishing vessels causes a particular problem. Nets which are discarded or lost can continue to catch or entangle marine life and, being non-degradable, they may act in this way for years (ghost-fishing). They can trap marine organisms when floating on the surface, when snagged on the bottom, or when drifting at some intermediate level. Marine mammals, fish, sea birds and turtles are among the animals at risk. There is also a degree of human risk to workers underwater who may become entangled in abandoned netting. Debris can also seriously affect shipping by fouling propellers, damaging drive shafts and clogging sea intakes and evaporators. The loss in productive time at sea and the costs of repair represent a clear economic detriment to maritime industries, and, in the case of fishing vessels, can reduce earnings significantly. A 1975

modified by the Protocol of 1978 relating thereto (MARPOL 73/78), in its Annex V, contains regulations for the prevention of pollution by garbage from ships, which entered into force in December 1988. These include prohibition of discharge to the sea of all plastics, such as synthetic ropes, fishing nets and plastic bags. Guidelines for the implementation of Annex V to the Convention request governments to consider a series of measures, including reporting systems, record books on board ships, compliance incentive systems and educational programmes.

59. The abandonment of trash such as worn vehicle tyres, discarded domestic equipment, cans and crates contributes to the unseemly aspect of many shores, especially those close to urban areas. In some instances, even medical and surgical equipment has been reported on beaches.

60. Educational campaigns will be a powerful tool in bringing changes in public attitudes towards the environment, and such campaigns have indeed been introduced since 1988 by many contracting parties to the conventions or protocols for the prevention of marine pollution by dumping of wastes. Nevertheless, more effort should be directed towards convincing the public and the authorities of the value and small personal cost of keeping the environment clean - at sea and on the beaches as much as along rivers, inside cities and on mountain slopes.

E. MANIPULATION OF HYDROLOGICAL CYCLES

61. Major changes in the pattern of river flows that are of significance to marine ecosystems can take place as a result of natural causes. The Yellow River in China, for example, has made several radical alterations of course during the past 4,000 years, entering the Yellow Sea at points varying by as much as 800 km. The changes introduced by the deliberate actions of man in directly exploiting river hydrology must be viewed in this perspective.

62. Man-induced alterations of river flow date back to ancient civilizations, but major dam building did not begin until the early twentieth century. The building of great multipurpose dams has accelerated since the 1950s with advances in engineering technology, particularly in the use of concrete. In the 1960s, 40 to 55 dams were completed each year, and recently the number of such schemes has increased substantially. In Africa and North America at least 20 per cent of run-off originates from impoundments; in Europe and Asia 15 and 14 per cent; in Australasian and South American areas, 4 and 6 per cent, respectively.

63. Rivers carry large amounts of dissolved and particulate material to the sea. Their discharges are highly variable, being determined by chemical, physical, and biological factors in the river basin. The global amount of sediment reaching the oceans is $13.5 \quad 10^3$ Mt y^{-1} but the paucity of accurate data, the difficulty of measurements during flood conditions and the degree of extrapolation needed makes estimates uncertain. The major physical and chemical influence of river discharges in the coastal receiving waters depends on their flow, which will be altered sub-

entirely held back. The effect on fisheries has been dramatic. Shrimp fisheries declined and the *Sardinella* yield of 18,000 tonnes in 1962 dropped to 2,000 tonnes in 1967 and remained between 2,000 and 3,000 tonnes until 1983. There are now signs that the yield is rising again, possibly in response to increased nutrient inputs provided by drainage waters from the irrigation of agricultural areas in the delta and improved fishing methods. Major coastal developments have also far-reaching effects on the species composition of adjacent waters (e.g. the opening of the Suez Canal on Mediterranean species) or on the nature of the ecosystem (e.g. tidal dams and barrages). Other types of barriers placed across rivers, such as tidal control gates, can lead to local mortality in downstream coastal shellfish beds and suspended fish culture cages during high flows.

69. In conclusion, manipulation of hydrological cycles on land can have adverse effects in the marine environment by changing the structure of ecosystems, diminishing the yield of fisheries and altering coastlines. Clearly, while dams and diversions are planned to benefit agriculture or other human activities, a balance must be struck between the positive gains expected at a local level and the probable, but more remote, adverse effects on the overall environment.

F. LAND-USE PRACTICES

70. While water diversion and dam building in inland areas have profound effects on the coastal zone by altering inputs of fresh water and sediments and by changing the physical characteristics of the coastline, a number of other activities conducted well inland also affect the sea and its resources. One of the most important of these is the intensive use of persistent agrochemicals, but deforestation, afforestation, irrigation and several other land-use practices are also significant. Their impact on the coast should be taken into consideration at the planning stage.

71. While it is apparent that large-scale clearing of forests and of grasslands generally results in more rapid run-off leading to soil erosion and increased sedimentation in coastal areas, the influence of trees varies with local topography, rainfall and soils. Large-scale afforestation in temperate climates has led to reduced river discharges by increasing evapotranspiration, and to changes in drainage-water quality, although the effect may be different in different edaphic and climatic conditions. Adverse effects also result from intensive farming practices. For example, intensive livestock rearing leads to high ammonia emissions with potential for soil acidification and more acidic drainage; overgrazing increases soil erosion, particularly in arid areas; disposal of animal wastes by land manuring or through sewers increases the organic load discharged to coastal areas.

72. The world-wide pressure to increase irrigation in arid areas has often led to adverse effects and will also have consequences in the long term for the marine environment. For example, irrigation water is often entirely consumed before reaching the coast, and any drainage from irri-

waters and more hostile environments. With the move towards stabilization of prices at lower levels in 1986, the trend in consumption has again been upward.

77. The general picture in the decade up to 1986 is of a dramatic drop of 25 per cent in the amount of oil moved by sea, 431 million tonnes less in 1986 than in 1977. This reduction took place almost entirely in the Middle East, the 1986 exports from that area being only 53 per cent of the 1977 figures, a reduction of 485 million tonnes. The main importing areas were still Western Europe first, the U.S.A. second and Japan third, but over the decade their imports were reduced by 34, 32, and 25 per cent, respectively. Another notable trend has been the steady increase in the transport of finished products (mostly non-persistent) in contrast to crude oil. In 1977 the transport of finished products represented 15 per cent of total exports but the figure had increased to 25 per cent by the following year, and crude oil exports were 33 per cent less.

78. Associated with the reduced transportation, the number of oil spillages at sea recorded by the International Tanker Owners Pollution Federation has declined steadily in the last decade, from an annual average of 670 events in the first five years to 173 in the last five. For major accidents with over 5,000 barrels (725 tonnes) spilled, the corresponding averages are 20 and seven events. It is particularly encouraging that decreases occurred not only in the absolute numbers of accidents but also in the rate. An analysis of casualty reports in Lloyd's Register of Shipping shows that the number of serious casualties in tankers over 6,000 gross registered tons (grt) average 2.5 per hundred ships in the period 1977-1981 but only 1.8 in the period 1982-1986. However, number is not the only aspect of casualties that must be considered, their magnitude and the circumstances in which they occur are as important (see section I J).

79. The reduction in the amount of oil carried at sea has not only decreased pollution because of the diminishing numbers of accidents, it has also cut operational inputs of oil and this has been aided by the entry into force of MARPOL 73/78. Annex I of this Convention requires, among other things, that a greater number of tankers be fitted with segregated ballast and crude oil washing systems, and that all must have effective oil/water interface detectors and overboard discharge monitors. Also, all vessels of 10,000 grt must be fitted with oil-water separators and oil discharge monitoring. In addition, special areas have been designated (Mediterranean Sea, Black Sea, Baltic Sea, Gulf Area, Red Sea and, since 1988, the Gulf of Aden) where there is total prohibition of all discharges from ships other than clean water.

80. These regulations have resulted in a major reduction of operational pollution, not only from tankers but also from all other types of vessel. There have been parallel national and international improvements in ship safety requirements and in traffic separation schemes in areas of high traffic density. In recent years there has been a major strengthening of enforcement procedures and vessel inspections, particularly by states that are major importers of oil.

diversity of climates. Drilling operations are now conducted even in such hostile environments as the Grand Banks, parts of the Georges Bank and the Beaufort Sea.

85. Environmental impacts are possible at all stages of oil exploitation. During the initial surveys to locate reserves, the explosives used can kill fish, and other seismic survey techniques interfere with commercial fishing. When a field has been identified, assessment of its potential involves exploratory drilling from ships or temporary platforms, which produce the same impact as any large vessel anchored for an extended period. The discharges of drilling mud may cause additional problems. Once the presence of hydrocarbons in commercial quantities has been demonstrated, production facilities are set up. These may involve gravel islands created from dredged material from nearby borrow pits or from onshore gravel deposits, with material trucked to the island site over substantial causeways. Such islands cause multiple impacts both by the associated dredging and dumping and by physical alteration of coastal processes.

86. The most common method of exploitation is from steel or concrete production platforms which may weigh many thousands of tonnes. The impacts of these structures stem partly from operational releases and partly from accidents. To some extent the latter can be avoided by good safety practice. Operational discharges are for the most part regulated by international agreements. In the North Sea, for example, oil in water discharges is limited to 40 ppm. Both exploration and production installations use drilling muds, which may or may not contain significant amounts of oil, and produce large quantities of cuttings, rock fragments derived from the drilling. The cuttings, separated as much as possible from the drilling muds (which because of their high cost are recovered and re-used as frequently as possible) are disposed of over the side of the platform. They accumulate on the bottom and may affect an area of up to 3 km radius around the platform, and cause obvious changes in the benthic communities there. The impact of normal operations is therefore significant but localized. For instance, only about 0.1 per cent of the North Sea is exposed in this way. Also, offshore wells can be a target for military action, as shown by recent events in the Gulf area, or sabotage, with consequent pollution of the neighbouring waters.

87. In addition to these environmental effects, oil exploitation has other impacts. The presence of rigs and pipelines creates exclusion zones for fishing vessels and other shipping, while the debris associated with offshore oil operations can damage fishing gear or entangle ships' propellors. In the North Sea, nearly six million pounds sterling have been paid out in compensation for loss of fishing gear by Norwegian fishermen and about 1,200 claims have been made by U.K. fishermen over the past 10 years for loss of gear and fishing time. An operation over eight years to remove 1,600 tonnes of debris from 6,300 km^2 of sea-bed in the Norwegian sector of the North Sea has cost an estimated 3 million pounds sterling. This clean-up in the Norwegian sector has been supported by improved charting of the seabed, by serious attention by the oil companies to prevent debris being dumped, and by stricter national regulations.

88. A further problem, only now emerging, is the question of decommissioning and disposal of oil installations. In some parts of the world platforms are reaching the end of their useful lives

cial islands in shallow water.

91. Effects will depend on the method of mining, the type of ore and the characteristics of the mine site, where disturbance will be caused in the water column and on the sea-bed. In the water column, surface turbidity plumes are created by those systems designed to pump ore in a slurry to a surface vessel, and also occur close to the sea floor if fine material is produced or is already present in the bottom deposit. The main disturbances are on the sea floor in the path of the collection machinery, and additional disturbances by noise and even light are possible.

92. Effects may be in the near or the far field. Near-field effects are those limited to the mine site and the period of active mining. There will inevitably be local impact on the bottom. Immobile and slow-moving benthic species and their habitats are affected, and spawning grounds of other species are damaged by the mining machinery. On a sea-bed subjected to wave action, shallow trenches in sand flatten in hours or months but in gravel, pits may take 25 years or more to fill. Such trenches, pits and mounds can cause problems for fishermen using bottom gear in the area, as can exposed or displaced boulders or discarded mining gear. Sand and gravel mining are effectively regulated in some countries.

93. Far-field effects are likely to be on the sea-bed, surface and mid-water effects being minimal. The two main factors are turbidity and sedimentation.

94. The direct physical effect of sedimentation is most important, although many burrowing organisms are able to work their way out as material is deposited. However, the scale and frequency of sediment discharge may exceed the capacity of benthic communities to survive or recover. Some organisms such as corals and bottom-spawning fish, which require clear water are particularly at risk from increased sedimentation. Other communities, for example the cobble-kelp community in the Arctic, and deep-sea environments which are slow to be recolonized, are also particularly vulnerable. Toxic substances in the original sediments are unlikely to be a problem in the far field.

95. In conclusion, while mineral exploitation in the sea does have measurable impact on the environment, this is likely to be limited to the site and the time of the operation, and can be reduced by careful planning and attention to operational procedures. Widespread adoption of recognized standards and criteria for these procedures would be useful. Standardisation of sampling, analyses and reporting of environmental information is desirable to obtain data that can be applied in different geographic or temporal contexts. Such data are required before the commencement of, during, and after the completion of mineral recovery operations so as to forecast and assess impacts.

I. EXPLOITATION OF LIVING MARINE RESOURCES

102. The first GESAMP report on the Health of the Oceans referred to the global fisheries yield, noting that the 1979 catch of 71.3 million tonnes represented an increase of about 1 million tonnes over the previous year and that annual increases were running at only 1-2 per cent, much lower than the 6-7 per cent increases of earlier decades. However, since 1979, the overall trend has been strongly upwards, with annual increases again in the region of 7 per cent. The most recently reported catch, for 1987, achieved a new record of 92.7 million tonnes, and preliminary figures for 1988 indicate a further increase to 94 million tonnes. It is now expected that the figure of 100 million tonnes, which many believed to be the maximum sustainable global yield of conventional fisheries, will be reached well before the end of the century. However, this progressive increase conceals great variability of natural resources and many problems.

103. A major part of this variability is due to natural causes, not least to El Niño-type events (see section I J) which result in changes in the distribution and abundance of the stocks of anchoveta and small pelagic fish, and alter the fishing patterns of several countries that contribute significantly to the global catch. In general, natural fluctuations are not clearly understood and their causes not known. Combined with excessive exploitation, the consequences for fisheries of these natural events seem to be much more important than any known pollution effect in open water.

104. A large number of stocks, especially those most valuable commercially, are fished at or beyond their maximum sustainable yield, and rational management is complicated by changes in the dynamic balances between species. Pressure on stocks is increased by new technology - the continued development of better vessels, improved fish-finding techniques, new gear, advanced handling and freezing facilities. Drift nets of monofilament nylon, for example, are now used on a large scale in the open ocean. In the South Pacific a fleet of 160 boats adopted this technique in 1988, and sets out each night over 60 km of netting, 60 m in depth, from each boat for tuna. A comparable operation takes place in the North Pacific for salmon. These nets catch dolphins, whales, turtles and seals as well as the target species and, used on a large scale, they represent a fishing effort that has not previously been thought possible in the open ocean.

105. Since the 13th century, whalers have been able to improve their catch by taking advantage of advancing technology to exploit more and more species, world-wide. Because whales are often dispersed through extensive sea areas and limited to slow rates of reproduction, the number of breeding animals within some of the most heavily exploited species is critical. While there is no firm evidence that any whale species has been lost, concern is expressed for species such as the Right Whale in the northern hemisphere, and the eastern Pacific Gray Whale. Formerly,

trial fisheries for small species and the juveniles of larger ones.

110. Human attempts to manage natural populations can have other effects. For example, conservation measures to protect seal stocks by preventing hunting and culling may increase their numbers, resulting in overcrowding and disease at haul-out sites and increased competitive pressure on fishery resources. In addition, seals are hosts to parasites, part of whose life cycle is completed in the flesh of commercial fish, and in several parts of the world fishermen complain that increased seal populations result in parasite levels in fish so high that the catch becomes unmarketable.

111. Although living marine resources are harvested largely for food, some species are utilized for other purposes. The exploitation of living corals, coralline algae and some molluscs for construction material can severely damage biological communities. The increasing importance and use of pharmaceutical products from marine organisms has resulted in small-scale harvesting of rare or uncommon species.

112. Mariculture, which is rapidly expanding worldwide (25-30 per cent per year in some countries), can also have substantial, if local, effects on the environment. If conducted on a large enough scale at a single site, it causes eutrophication, reduces visual amenity, and can interfere with other uses of the sea. In particular, cage culture brings together large numbers of fish in a relatively small space, releasing substantial quantities of uneaten food, and of faeces and other excreta. Less evident problems associated with mariculture are posed by the use of growth-enhancing and therapeutic agents, and pigments. Of the vitamins, biotin and B12 have a short half-life in the sea but may stimulate plant growth briefly. Little is known about the fate of dosed pigments and antibiotics.

113. Another concern is the use of antifoulants to protect the nets, cages and other structures of fish farms. For example, organotin compounds have been found as contaminants of the environment around mariculture establishments in North America and the U.K. and have marked effects on non-target organisms. Other biocides recently introduced to protect salmon from ectoparasites, such as dichlorvos - an organophosphorus compound - are a cause of concern.

114. However, the most widespread pollution effects from cage culture are due to organic enrichment generated around sea cages where the organic content of sediments can be up to 20 times higher than in more distant, unaffected, areas. This results first in reduced species diversity, and in extreme cases the benthic invertebrates in the immediate vicinity of the cages are totally eliminated, with hypoxic conditions extending into the water column.

115. Comparable effects arise from mollusc (e.g. mussels) culture even when additional food is not supplied. On a global scale, the impact is small and the affected areas can be reduced by careful site selection and the use of improved culture systems, such as holding facilities which allow waste containment. However, where there is intensive cultivation and the available sites are limited, the local effect can be serious, and several governments have introduced licencing and other

beaches and mangrove stands were also severely affected.

119. Apart from disturbances due to such relatively frequent events, there are major anomalies of the atmosphere and ocean circulation that can cause widespread adverse effects. The best known example is El Niño. As a result of a sequence of complex meteorological and oceanographic events originating in the tropics and recurring at irregular intervals, warm (28-30° C) waters flow into the South East Pacific Ocean, especially off the coast of Ecuador, Peru and Chile. The 1982/83 El Niño was one of the most severe recorded and its consequences were dramatic. In 1983, the yearly rainfall in Colombia was twice the average. In June of the same year, rainfall was 40 times the monthly average at Guayaquil (Ecuador) and 340 times the monthly average at Paita (Peru). Rivers swelled and landslides destroyed entire slopes of the Andean ridges. Populated areas and agricultural land were swept by torrential water and mud flows, with major loss of human life. Sea level rose by as much as 40 cm and large swells striking the South American shore caused a retreat of the coast, inundated lowlands and destroyed fishing and aquaculture installations. The inflow of warm waters led to the immigration of tropical fish and the disappearance of commercial endemic species, halting the operation of fishing fleets, with a total loss to the fishing industry in Ecuador and Peru in excess of US$200 million.

120. Recurring natural disturbances are well documented also at the biological level, with many records of red tides, exceptional algal blooms, and population explosions of a number of animal species, including jellyfish in the Black Sea and the Adriatic; the reef-burrowing sea urchin *Echinometra mathaei* in Kenya and Kuwait; the coral-eating gastropod *Drupella* in the Philippines, Japan and Okinawa, and the crown-of-thorns starfish *Acanthaster planci* in many areas. Population declines are also reported, such as mass mortalities of the sea urchin *Echinothrix* in Hawaii and throughout the Caribbean. On more local scales, there are many records of mortalities of marine organisms such as the sea-birds in the Irish Sea in 1969, and of fish and invertebrates off the North East coast of North America in 1976 and off Norway in 1988, sometimes associated with unusual phytoplankton blooms. In addition, a viral epidemic has been killing thousands of common seals in the North Sea since early 1988. Paradoxically, some limited but recurring natural disturbance will, in many ecosystems, help maintain the ecological balance.

2. *Accidents*

121. In several of the foregoing sections, reference has been made to accidents, both ashore and at sea, as a source of marine pollution. The effects even of the most dramatic accidents occurring well inland, such as the Chernobyl accident (1986) and the Basel factory fire (1986), which polluted the river Rhine, were not, or barely, detectable in the sea. The accidents of greatest marine significance are more likely to be those which occur at installations directly on the coast, or on ships or rigs at sea. While a great diversity of chemicals may be involved, in the last decade most of the accidents have been associated with oil. The loading and unloading of cargoes and fuel tanks result in frequent, but usually small, spills at ports, terminals and storage facilities, but the

II. MARINE CONTAMINANTS: LEVELS AND DISTRIBUTION

A. TRANSPORT AND FLUXES

126. There is a wide diversity of pathways by which contaminants reach the marine environment. Over 40,000 km of actively divergent plate boundaries lie beneath the world oceans. Not only are the active areas a continuous major source of heat, but intermittent ejection of molten magmatic and hydrothermal fluids produce massive underwater clouds of sulphur and metallic compounds at high temperature. Such clouds or plumes with dimensions measured in tens of kilometres have been observed for example in the vicinity of the Explorer Ridge off British Columbia and thermal vents have been detected in many ocean areas. Few quantitative data are yet available on these natural inputs, but their magnitude implies that they are significant on a global basis. However, the two dominant pathways by which potential pollutants reach the oceans from the continents are rivers and the atmosphere. If these inputs to the oceans are to be controlled, attention should be directed to the processes by which contaminants initially become entrained in rivers and atmosphere. To judge the need for, and value of, such controls, some assessment of the relative importance of each pathway is required.

1. River input to the sea

127. The land-sea flux from rivers can be considered as made up of the gross flux, i.e. the rate of contaminant transport to the sea from within the river catchment itself, and the net flux, i.e. the flux of river-derived material that escapes from the nearshore and estuarine region and is transported to the open ocean.

128. The most reasonable way of estimating the global gross flux from rivers to oceans is to extrapolate flux data obtained from rivers representing a range of climatic, geological, biological and demographic regimes for which reliable data are available. At present, this is possible for only a small number of river systems and a few contaminants. In dealing with nutrients, for example, a variety of river systems has been studied and the results extrapolated to provide an estimate of the total global gross river input, giving figures for the natural fluxes of dissolved nitrogen, phosphorus and silicon and for the fluxes of suspended nitrogen and phosphorus.

129. The fluxes resulting from human activities have also been estimated by a variety of other approaches, including comparison of pristine and polluted rivers, historical evolution of

amounts entering directly in gas and particulate phases (dry deposition) and of those falling out as rain and snow (wet deposition). It is difficult to obtain an accurate estimate of either. Even when contaminant-free samples of precipitation are available, and this is particularly difficult to achieve over the oceans, interpretation of the data is complicated because chemical composition varies with differences in vertical distribution, duration, intensity and droplet size of the precipitation. Even greater difficulties are encountered in making direct measurements of "dry" particulate deposition. Finally, techniques are not at present available to make direct measurements of the relevant gas fluxes across the air-sea interface.

135. Because of these problems, indirect methods have been developed for the estimation of contaminant fluxes. Most estimates are of gross rather than net flux, since some chemicals entering the ocean from the atmosphere can be re-injected to the atmosphere via bursting bubbles or gas exchange. Unless this recycled material can be taken into account, the calculated deposition may be anomalously high. Existing data bases suitable for estimating the air-sea flux vary in size and quality, and few are extensive enough in time and space to take account of the variability in atmospheric (and water) concentrations and deposition rates, although this is improving in some ocean basins, particularly the North Atlantic and North Pacific.

136. Some data are available from the North Sea, the Baltic Sea and the western Mediterranean, as well as from areas of the Pacific and Atlantic Oceans. Extensive evaluation of data from these and other sites indicates that atmospheric fluxes of many metals (excluding mercury) to the North, Baltic and Mediterranean Seas are three to 10 times higher than those to the open North Atlantic. Fluxes to these regional seas are 10 to 100 times higher than those to the tropical North Pacific, while fluxes to the South Pacific are lower than those to the North Pacific by a factor of five to ten. These flux differences are consistent with the increasing distances from continental sources, both natural and anthropogenic. Mercury shows relatively small flux differences because it is found in the atmosphere primarily in the gas phase as elemental mercury, which has a relatively long atmospheric lifetime and therefore a relatively homogeneous geographic distribution.

137. Similar atmospheric flux estimates have been made for some high molecular weight organic compounds such as PCBs, DDT and HCH to the European regional seas as well as the open Atlantic and Pacific Oceans. Although there are even greater uncertainties, a trend of decreasing atmospheric fluxes can be seen between the regional seas and the northern hemisphere open oceans of roughly a factor of two to five, with fluxes to the southern hemisphere oceans generally a factor of two to five lower still. The overall decreases in flux are less than for most of the metals studied because, like mercury, the organic compounds are found predominantly in the gas phase and have a longer atmospheric residence time than metals associated with aerosol particles.

138. Finally, the fluxes of fixed nitrogen species show the same type of gradient from the regional seas to the South Pacific, but the gradient is again less marked than for metals, despite the

from 30 to 200 ppm in most samples, of which five to 10 ppm are attributable to known contaminants such as DDT, PCBs, dioxins and chlorophenols. The rest (up to 95 per cent) is unaccounted for. Possible sources may be low-molecular-weight compounds from pulp mills, from aluminium and magnesium smelters, and from the burning of chlorine-containing materials. Clearly, much more needs to be known about the life history of chlorinated compounds released to the environment.

143. Chlorinated hydrocarbon pesticides and PCBs (polychlorinated biphenyls) are a source of special concern because of their persistence in the environment, their concentration along food chains and their long-lasting storage and accumulation in the fatty tissues of animals, reaching the highest levels in raptors and marine mammals. These substances, after reaching the sea mostly through the atmosphere, become adsorbed to suspended particles and tend to settle in sediments. They will remain there until mobilized by disturbances of the sea floor and so possibly reintroduced into the food chain, regardless of whether their use has been discontinued on land.

144. Data on production and use of pesticides and PCBs are lacking for most parts of the world. In most countries in the temperate latitudes chlorinated pesticides have been banned and are being replaced by less persistent products. PCBs have been used since the 1930s for a number of purposes - as dielectrics in transformers and capacitors, form which they can normally be recovered without loss, and as hydraulic and heat-transfer fluids as well as components of a number of products such as paints and lubricating oils. When not used in strictly controlled closed systems, they can spread and eventually reach the sea. Despite the phasing out of their use in non-closed systems in a number of countries, they continue to be released to the environment, for instance from dumps and landfills. In lower latitudes, environmental measurements indicate that chlorinated pesticides, including DDT and HCH (hexachlorohexane) are widely applied, and suggest that the use of PCBs is increasing. As a result, DDT, HCH and PCBs are now clearly measurable even in the Antarctic environment, though at levels lower than in temperate latitudes.

145. While global time trends in the concentrations of these substances are not known because improved analytical techniques make it difficult to compare past and present results, there is strong evidence that ocean surface waters have highest concentrations in the northern temperate latitudes and lowest near the poles. Likewise, specimens of marine mammals from the northern hemisphere have higher levels of PCBs in their fat than those from the southern hemisphere. The latitudinal difference is less for DDT.

146. The biocidal properties of organotin compounds, especially tributyltin (TBT) were recognized in the early 1950s. Initially, these substances were used as fungicides, bactericides and preservatives for woods, textiles and paper, and for electrical insulation. TBT was first introduced as an antifouling agent in marine paints in the mid-1960s. It also enters the marine environment as a result of a variety of other uses. For instance, it is, or has been, applied in antifouling preparations on the net cages used in salmon farms, and it is used in some countries on lobster pots and pounds for keeping fish and shellfish. It was known to be highly effective, and laboratory tests

areas. The experience of DDT suggests that a watch should be continued on TBT uses and fate, as well as on the possible effects of its substitutes.

2. Radionuclides

152. Radioactive substances are present naturally in ocean waters. Among these are radioisotopes of potassium, rubidium, thorium and uranium, the last two always accompanied by their radioactive disintegration products. Other radioactive substances, ^{3}H and ^{14}C, originate in the atmosphere through the interaction of cosmic radiation from outer space and the constituents of the air, and can also be produced in the course of human activities.

153. The first group reaches the oceans mostly as a result of run-off from weathered rocks or, in the case of their disintegration products, by decay of the primordial substances in the water itself. In contrast, cosmogenic radioactive substances are deposited on the surface of the ocean by precipitation. Both categories of substances are then distributed through the water column by physical, chemical and biological processes, and subsequently deposited in the ocean sediments. The inventories of, e.g., ^{14}C, ^{3}H, ^{40}K, and ^{238}U in ocean waters have been estimated to be 8.0 10^{3}, 8.5 10^{2}, 1.6 10^{7}, and 5.6 10^{4} PBq (petabecquerels), respectively.

154. Human activities add to the inventory of ocean radionuclides. Naturally-occurring radionuclides are leached from mine tailings and milling wastes but give rise to measurably increased levels only close to their sources. Elsewhere, their contribution is negligible or at least not measurable.

155. Nuclear weapons tests have introduced artificial radionuclides into the environment. Most of these have arisen from tests in the atmosphere and fallen out through dry and especially wet deposition. Artificial radionuclides produced by such tests include ^{14}C, ^{137}Cs, ^{3}H, and ^{90}Sr, as well as plutonium and other transuranic elements. Rough estimates of the inputs of these radionuclides to the oceans have been derived from information reviewed by the United Nations Committee on the Effects of Atomic Radiation (UNSCEAR) in its 1982 report. The estimates of input were 6.1 10^{2}, 1.5 10^{5}, 8.2 and 3.7 10^{2} PBq for ^{137}Cs, ^{3}H, $^{239,240}Pu$ and ^{90}Sr, and not less than 40 PBq for ^{14}C, respectively.

156. The inputs to the oceans in the southern hemisphere have been half of those in the northern hemisphere. Recently an IAEA Expert Group has obtained slightly higher estimates of the ocean inventories of these radionuclides on the basis of measured concentrations. Fall-out from nuclear tests has been the only source of world-wide radioactive contamination of the oceans. However, its widespread dispersal has resulted in low-level ambient concentrations and hence in negligible additions to the exposure from natural background.

157. Operational discharges of effluents containing radioactive material from nuclear reactors and reprocessing plants make an additional contribution to the radionuclide inventory. The

b. notwithstanding the very small risk to individuals, the aggregate exposure of the global population from long-lived components of the dumped waste imply that the total casualties resulting from past dumping may be up to about 1,000 cases spread over the next 10,000 years or so. The dominant pathway for this exposure would not be via shellfish consumption, but associated with the consumption of food produced on land. The reason for this is that the main contributor to these casualties (or to the collective dose commitment, as it is known technically) is the isotope ^{14}C which has a half-life (i.e. time required for its activity to decrease by 50 per cent) of 5,700 years. Over such a period much of it would escape from the ocean as gaseous carbon dioxide and spread throughout the world. If ^{14}C, and a few other long-lived radionuclides, were to be removed from the waste before disposal in the ocean, the collective dose commitment from future dumping operations would be very much reduced, although it should be appreciated that other means of disposal of ^{14}C might carry risks comparable to those associated with sea dumping;

c. the incremental dose from past dumping to individual marine organisms on the sea floor at the dump site or nearby will be significantly less than the dose that the organisms receive from naturally-occurring radionuclides, and hence is not expected to cause any detectable effects on populations of organisms.

160. Radionuclides in the sea may contribute to internal or external exposure of organisms, including man, through several pathways. Those related to internal exposure are the consumption of various types of seafood and the inhalation of airborne particulates and marine aerosols. External exposure may occur during swimming, boating and other beach activities. It may also result from the handling of contaminated fishing gear. Some pathways, while of scientific interest, do not lead to significant exposure from radionuclides. For instance, bubble scavenging in the water column coupled with droplet ejection from bubbles bursting at the surface may be a mechanism for transfer of radionuclides and heavy metals from sea to air and subsequently to land. This has been demonstrated for plutonium and americium in the Irish Sea, but the radiation dose from large droplets introduced in the surf zone is negligible compared with that received by the critical group from seafood consumption. However, small droplets generated by bubble bursting may make a measurable contribution to levels of plutonium near the coast.

161. Nuclear accidents have not contributed significantly to the ocean inventory of radionuclides on a global scale. Although three major nuclear accidents (Windscale, U.K., 1957; Three Mile Island, U.S.A., 1979 and Chernobyl, U.S.S.R., 1986) have resulted in radionuclide releases to the environment, the major pathways leading to man were not marine. In the Windscale accident, the principal route for irradiation of man was radioiodine in milk. At Chelyabinsk exposure resulted mostly from ^{90}Sr - contaminated milk and from external irradiation. At Three Mile Island most of the release consisted of radioactive noble gases, especially ^{133}Xe. The releases from the Chernobyl accident gave rise to widespread contamination of the environment throughout Europe and to exposures of the population mainly from gamma emitters deposited on the

recognisable. This may account at least partly for the concern still widely expressed about it as a marine contaminant. The major source of input to the oceans is from shipping, which is dealt with in section I G. Spills in restricted areas have dramatic local impact, as discussed in section I J. This section discusses an aspect which is causing problems around the world, pollution from the most persistent fraction, oil tar. This originates when evaporation of the light fractions of hydrocarbon compounds released to the sea leaves flakes, lumps or balls which float and are distributed widely by winds and currents. About one per cent of oil released to the sea forms floating tar, and much of this originates from tanker sludges, but a variety of other sources contribute. Tar eventually drifts on to beaches and accumulates there.

168. In some parts of the world where shipping, particularly tanker traffic, is heavy, especially in semi-enclosed seas, the effect on beaches can be dramatic. In the Red Sea, for example, and in the Kuwait/Oman area, which probably receive more oil pollution than anywhere else in the world, tar abundance on beaches is sometimes as much as 100 times higher than in other regions. Weights of 1 kg m^{-1} of coastline are common in this region, and values of up to 30 kg m^{-1} occur. In places, weathered oil pavements many centimetres thick blanket sandy beaches and rocky promontories and cover the aerial roots of mangroves. These are extreme conditions, but the situation in many other parts of the world also gives cause for concern. For example, in the wider Caribbean, which is a region of very significant hydrocarbon production, oil is an ubiquitous marine contaminant, damaging the important tourist industry. It is estimated that the use of beaches by tourists is adversely affected when tar levels reach 10 g m^{-1} of beach front. Many beaches in the Caribbean have average concentrations in excess of 100 g m^{-1}, a level at which beaches become virtually unusable for recreation. A comparable situation is found for Indonesia and the Philippines, in India (particularly its West coast) and Pakistan, in parts of West Africa and the Mediterranean, and, although with less impact, at most windward beaches in other parts of the northern hemisphere. By contrast, many beaches in the southern hemisphere are relatively unspoiled.

169. There is broad agreement, confirmed by many surveys, that since 1979 there has been a significant reduction in beached tar around the world. In some countries this can in part be accounted for by systematic and regular cleaning of beaches. Two more general factors are the reduction in marine transportation of oil following the price crisis of 1979 and the entry into force in 1978 of the 1969 amendment to the international convention OILPOL 54. This amendment permits the release of oil from tankers only in restricted areas and, even there, only at certain rates and quantities. Further, MARPOL 73/78, which replaces the OILPOL Convention, in its Annex I (which entered into force in 1983) provides for the designation of "special areas" within which tight control of pollution is required, and this has been adopted, for example, in the Mediterranean Sea. There is, however, no cause for complacency. Many beaches remain spoiled by tar, and a more stringent enforcement of the relevant regulations is desirable.

consistent and comparable results. The value of and necessity for these exercises have been well demonstrated, and it is recommended that they be continued and extended.

175. Inevitably, the poor comparability of earlier data limits their use. Often results have not been screened before storing in data banks and the propagation and use of invalid data is a cause for serious concern. It is recommended that regional or global data banks should contain only validated data collected for a defined purpose, and that the purpose should be clearly stated. In all cases their quality should be indicated, and it should always be possible to link the recorded data with detailed information on methods of handling and analysis, quality assurance procedures and other information relevant to assessing data quality.

2. *Concentrations in water*

a. *Open-ocean waters*

176. Of the metals selected for review, mercury does not display any distinctive depth distribution in the oceans, at least on the basis of the data available. Measured concentrations in ocean waters range from 0.37 to 7.0 ng l^{-1} though representative levels tend to be around 1 ng l^{-1}. In the northwest Atlantic concentrations are about twice those of the northeast Pacific, while in the western Pacific there is some evidence that mercury decreases along a north-south gradient, possibly as a result of atmospheric transport from the continents and deposition via rain. With regard to semi-enclosed areas, mercury concentrations in the North Sea and the Baltic Sea are similar to those in the north Atlantic; this may also be true of the Mediterranean, although reliable data are few.

177. For cadmium, reported concentrations in surface waters are more variable, from 0.2 to 200 ng l^{-1}. The lowest concentrations (up to 10 ng l^{-1}) are found in the open ocean, particularly in the subtropical and central gyres, with higher levels (up to 200 ng l^{-1}) in enclosed seas, such as the Baltic and the North Sea, enhanced by river inputs. River inputs are also proposed to explain a significant inshore-offshore gradient from 22 to 0.22 to ng l^{-1} in the north-west Atlantic, while in the north Pacific the higher inshore values are attributed to upwelling. Unlike mercury, cadmium shows a nutrient-like distribution, being low in surface waters and increasing with depth.

178. The concentrations of lead in the open north Atlantic and north Pacific oceans range from 5 to 50 ng l^{-1} in surface samples. Its vertical distribution - eight to 10 times greater at the surface than in deeper layers - differs from that of cadmium, and is attributed mainly to atmospheric inputs arising from emissions from smelters and combustion of leaded petrol. These probably determine the latitudinal distribution, accounting for the threefold higher levels in the north Atlantic compared with the north Pacific, and for the eight to 10 times higher values in these northern areas compared with the south Pacific. There is some evidence that lead levels in the open north Atlantic are decreasing in response to a general reduction in the use of leaded petrol in North America over the last 10 years.

187. Chlorinated hydrocarbons in coastal waters have their highest levels in industrialized zones, reaching 370 ng l^{-1} for PCBs in the Seine estuary, but values are usually much lower elsewhere, in the range 1 to 10 ng l^{-1}. DDT residues are generally below 5 ng l^{-1} in coastal waters, although, again, much higher levels have been reported near sources.

188. Coastal or semi-enclosed marine waters are characterized by enhanced levels of the nutrients nitrogen and phosphorus, as well as dissolved and particulate carbon. This contrasts with the levels of these nutrients in open oceans, which are usually close to levels of routine detection. Phosphorus occurs in both particulate and colloidal states, as well as dissolved as inorganic and organic phosphate compounds. Concentrations of phosphate in inshore waters range *from 1 μg l^{-1} P /PO^4 in oligotrophic areas of* the Mediterranean to about 10 μg l^{-1} in the eutrophic northern sector of the Adriatic. Levels of 20 to 30 μg l^{-1} are reported for the period 1980-84 in the Skagerrak.

189. Nitrogen occurs as dissolved inorganic nitrate, molecular nitrogen, nitrite and ammonium, and as organic nitrogen (e.g. urea, amino acids). Concentrations of nitrogen in the Mediterranean are reported as 14 μg l^{-1} N /NO3 and in the northern Adriatic 70 μg l^{-1}. Values from 10 to 200 μg l^{-1} occur in the Skagerrak.

190. There is evidence from estimates of discharge loads, as well as from measured concentrations, that levels of nitrogen and phosphorus have risen in the past 20 to 30 years. In the Baltic Sea, for instance, discharge has increased by factors of four for nitrogen and eight for phosphorus, while sea-water concentrations have increased two- or threefold for both. In the southern North Sea, both are considered to be about twice "background" concentrations. The extent to which these concentrations will be reflected in open-ocean situations is determined by the physical diffusion and dilution of nutrients as well as by the uptake by organisms.

3. *Concentrations in sediments*

191. Contaminant concentrations in sediments reflect both local mineralogy and the nature and origin of the sediments (e.g. grain size, clay and organic content). Sediment heterogeneity and the large variations in measurements of contaminant concentrations in sediments make data interpretation difficult.

192. Information on deep-sea sediments is sparse but there also the range is considerable. Mercury measurements in sediments from the deep north Atlantic, for example, range from 0.01 to 0.6 ppm, although levels may be even higher in areas subject to volcanic or tectonic activity. Cadmium in deep-sea sediments is usually less than 0.5 ppm and lead ranges from 3 to 60 ppm. The data for chlorinated hydrocarbons in deep open ocean sediments are sparse, being apparently limited to samples taken during a series of cruises in the Mediterranean where values reported ranged from 0.6 to 8.9 ppb in 1975-77, and to a single core from the Sargasso Sea in 1974 .

4. Concentrations in organisms

198. Mercury and cadmium have been measured extensively in mixed zooplankton samples from the Mediterranean, where concentrations are around 0.1 and 2 ppb, respectively. There mercury levels in krill (euphausiids) are similar to those in mixed zooplankton, but cadmium concentrations are much less. Bentho-pelagic oceanic rat-tail fish (*Coryphenoides armatus*) from the north Atlantic and the north Pacific have very similar levels of cadmium (0.025 - 0.027 ppm) and lead (0.012 - 0.016 ppm). For mercury, analyses of recently caught deep-sea fish compared with those of museum specimens collected in the 1880s suggest that no significant increase has taken place during the past century. Thus there is no evidence that the mercury found in deep-sea fish is related to human activities.

199. Arsenic is present in marine algae, typically at 10 to 100 ppm, about three orders of magnitude above levels in sea water. It is present in both water- and lipid-soluble forms and occurs as arsenobetaine in plankton and benthos, from which it is transferred via the food chain to molluscs (1 to 25 ppm wet weight) and shrimps (1 to 50 ppm wet weight) and eventually to man. In shrimps, much of the retained arsenic is in the exoskeleton, and is lost at moult. Pacific fish have 0.3 to 11.5 ppm wet weight and Atlantic fish 1 to 9 ppm. Data for marine birds and mammals are few, but shore birds have 0.01 to 1.5 ppm wet weight. Thus there is no evidence of biomagnification through the food chain.

200. Selenium displays behaviour similar to that of nutrients. It is selectively assimilated by phytoplankton and is further accumulated by marine organisms through food uptake. In uncontaminated areas, concentrations in molluscs are 0.4 ppm wet weight (*Mytilus*) and 3.5ppm (*Ostrea*), and 0.2 to 2.2 ppm in crustaceans. Levels in fish are variable, 0.2 to 1 ppm wet weight, with large predators having concentrations as high as 4.3 ppm in muscle, and even higher in the liver (13.5 ppm). Marine mammals may also have high levels in livers, 46 to 400 ppm, but muscle tissue has much lower concentrations, about 0.5 ppm.

201. Data on chlorinated hydrocarbons in open-ocean plankton are sparse. In the case of PCBs, variability is high, concentrations in Atlantic samples being two orders of magnitude higher (about 400 ppb) than those in Pacific samples (less than 2 ppb) and almost an order of magnitude higher than in the Mediterranean (around 7 ppb). The Atlantic measurements, however, were made in the early 70s and the reported levels may merely reflect the higher inputs into the waters that were prevalent in those years.

202. Observations on rat-tail fish collected at 3,000 m depth in the north Atlantic show clearly that chlorinated hydrocarbons (PCBs, DDT and degradation products, but also hexachlorohexane, toxaphene and chlordane) have reached the deep ocean, demonstrating transfer through food chains.

203. Concern has developed recently in Scandinavia and North America about the presence of chlorinated dibenzo-p-dioxins and dibenzo-p-furans in organisms living in the vicinity of pulp

variability in all regions is large, often by up to three orders of magnitude. This fact alone severely limits intra- and inter-regional comparisons.

209. A striking feature of recent data is the continued widespread occurrence of DDT residues and PCBs in marine organisms. The highest values are found in organisms from areas with known industrial and agricultural inputs (e.g. Buzzards Bay and Bedford Harbor in the U.S.A., the estuary of the St. Lawrence in Canada and Osaka Harbour in Japan), and the lowest in organisms from less contaminated areas such as the Arabian Sea and the central coast of Brazil. Most of the data reviewed had been generated during the 1980s, i.e. long after restrictions had been placed on the use of DDT and PCBs in developed countries.

210. Although continued and consistent time series are difficult to obtain, a recent analysis of the results of different U.S. monitoring programmes carried out through the 1970s to the 80s provides some indication of trends. In the Southern California Bight, PCB levels in Dover sole (*Solea solea*) fell by more than an order of magnitude (from about 1 to 0.03 ppm) between 1972 and 1981. Likewise, levels in mussels near the Los Angeles County sewer outfall decreased tenfold (from 2.5 to 0.24 ppm) between 1971 and 1978 but rose again to 0.56 ppm in 1979. An approximate and consistent threefold decrease in PCBs between the mid-70s and the early 1980s in samples of water, particulates and organisms from a single site in the northwestern Mediterranean has been observed by the same analyst using the same method throughout the whole period of monitoring.

211. Convincing evidence of decline in the regional use of organochlorine compounds between the 1970s and the 1980s comes, for example, from studies of Arctic seals. In seals from the Canadian east coast DDT residues declined three- to fivefold between the early or mid-70s and 1982, whereas PCBs fell by about half over the same interval. In Arctic ringed seals from the west coast of Canada, PCB levels declined by about the same factor. DDT levels, however, changed little during the same period, suggesting that continued use of the pesticide maintained an input to the western Arctic.

212. While the declining PCB levels are concurrent with the ban on the manufacture of these compounds in the early 1970s, DDT is likely to have been transported by the atmospheric route to the Arctic from parts of Asia where it is known to have been used extensively until at least the late 1970s.

6. *Conclusions*

213. Relative concentrations in different ecological compartments (water column, sediments, organisms) are valuable in developing models of transfer from source to target, in establishing spatial and temporal trends, and possibly in identifying a mechanism for toxic action. Analyses of environmental samples are often used in monitoring programmes to signal contamination by potentially hazardous agents. It must be emphasized, however, that these data, in themselves, do

III. BIOLOGICAL EFFECTS

217. This chapter discusses some of the most critical topics for the assessment of the state of marine ecosystems and of human health in relation to the marine environment. A brief reference is also made to biological data quality assurance as was done earlier (section II C[1]) in the field of chemical analysis, for which the needs for quality control, data validation and good management are better recognised. There are comparable needs in biological studies but rigorous quality control is often not sufficiently practised.

A. HUMAN HEALTH EFFECTS

218. Although the sea provides an important source of human food and an attractive environment for recreation, sea water contains a wide variety of agents, biological as well as organic and inorganic, all of which can be a hazard to human health. Use of the sea and its living resources determines the extent to which health is affected.

219. Rapidly expanding and, in many cases, seasonally increased coastal communities and discharges from rivers draining agricultural and industrial areas are the prime source of anthropogenic contaminants in the nearshore marine environment. The principal problem for human health on a world-wide scale is the existence of pathogenic organisms discharged with domestic sewage to coastal waters, estuaries or rivers and drainage canals that carry these organisms to the sea.

220. Bathing in waters receiving such inputs, and consuming contaminated fish and shellfish, are the causes of a variety of infections. Chemical contamination of sea water is also a potential threat to human health, while tainting and spoilage of seafood is of economic concern. It should be emphasised, however, that the problems are not entirely man-made. Naturally occurring aquatic biotoxins are also a health hazard, particularly in the tropical and subtropical waters of the Pacific and Caribbean Regions.

221. Several bacteria (e.g. halophilic vibrios) pathogenic to man are indigenous to estuarine and sea waters. Man is also exposed to parasitoses from the consumption of fish infested by worms such as *Anisakis* that have a complex life cycle through marine mammals and sea birds.

contaminated water are very effective carriers of the viruses.

226. The prevalence of these infections is largely determined by cultural habits governing the consumption of shellfish. Gastro-intestinal infections, and cases of diarrhoea and viral hepatitis have been reported from much of the West African coastline, the Asian seas, the Pacific and the Caribbean. Many investigations have shown high counts of indicator organisms (total and faecal coliforms) as well as of bacterial and viral pathogens in sea water, in bivalves and in sediments.

227. Massive outbreaks of infectious hepatitis and cholera associated with the consumption of raw shellfish harvested from wastewater-polluted coastal areas have brought public attention to this problem. Strict standards for shellfish and shellfish growing waters have now been widely established but only a small fraction of the incidents are reported.

228. Recent studies suggest that, even inland, a substantial proportion of all cases of endemic infectious hepatitis is associated with the consumption of raw bivalves including, in some cases, those harvested under what are currently considered acceptable sanitary conditions. An investigation in one European country has detected a high level of enteric virus contamination in shellfish samples from a major urban market. The new findings raise important questions about the adequacy of current shellfish sanitary practices, including handling and storage, and point to the need for a careful re-evaluation of existing standards and regulations.

229. In conclusion, the present state of knowledge indicates that the most clearly identified health risk associated with coastal marine pollution by urban wastewater is the transmission of disease by the consumption of raw shellfish harvested in contaminated areas. Monitoring and control of the wholesomeness of marketable shellfish should therefore be further strengthened, effective depuration methods employed consistently, the conditions of shellfish beds supervised more effectively and beds exposed to sewage-contaminated waters excluded from harvesting.

2. *Chemical contaminants*

230. Chemicals with a potential to cause harm to human health if ingested with seafood are present naturally in sea water and their concentrations can be increased by man's activities. Natural levels in sea water are usually low (mostly ng l^{-1}), but the relatively elevated concentrations of mercury (μg l^{-1}) in predatory fish in the Mediterranean and in the Seychelles Islands, and of cadmium in crabs from the Orkney Islands off Scotland and copper in the estuarine fauna of Cornwall are striking examples of geologically associated contamination. Studies in these regions have shown that, although exposure levels are much higher than elsewhere, no clinical effects have been detected among consumers. In general, the risk from exposure to naturally occurring chemicals is considered to be low.

231. Anthropogenic inputs of chemical contaminants, mainly originating from industrial discharges to estuaries or coastal waters, can result in locally much higher concentrations and

shellfish in many countries. The contamination of shellfish with diarrhoeic toxins (okadaic acid, dinophysistoxins and pectenotoxins) causes severe gastro-intestinal disturbances but no fatalities have been reported. The dinoflagellates responsible can contaminate shellfish at low cell densities, well below those which alter the colour of the water, so phytoplankton monitoring is necessary.

236. Dinoflagellates that produce ciguatoxins contaminate a variety of tropical and sub-tropical grazing fish, particularly in the southeast Asian seas and the Pacific, where the human disease ciguatera, characterised by neurological, cardio-vascular and gastro-intestinal symptoms, has emerged as a major constraint to fisheries development. Human exposure occurs through eating predator fish that feed on the grazers. As many as 50,000 individuals may be poisoned annually, with fatality rates from 0.1 to 4.5 per cent. Temperate countries are involved through imports of tropical fish. The annual cost to fisheries in Florida, the Caribbean and Hawaii from lost business, exclusive of legal actions, is estimated at US$ 10 million. Approximately 2,300 cases occur in the U.S.A. and Canada each year, costing up to US$ 20 million, mainly due to time off work and hospitalisation. No effective monitoring programme has yet been developed.

237. Apart from dinoflagellates, other flagellate groups, often small species in the size range 10-20 μm have recently been implicated in toxic episodes, and major problems are reported in both brackish and sea water, particularly from Israel and Japan. The full extent of the threat from aquatic biotoxins is not at present well understood and the possibility of encountering unexpected situations or even new biotoxins is well illustrated by a recent event in Canada.

238. This concerned an outbreak of shellfish poisoning resulting from eating blue mussels contaminated with the neurotoxin domoic acid produced by the diatom *Nitzschia pungens*. It is referred to as amnesic shellfish poisoning and caused neurological symptoms, including memory loss, and human fatalities, and led to the closure of shellfish beds. While a particular concern at the time was that the production of domoic acid was previously unknown, subsequent work suggests that this toxin is a relatively common product of *Nitzschia pungens* but was detected only when the incident of acute shellfish poisoning occurred in 1987.

4. Conclusions

239. Cases and outbreaks of gastro-enteric diseases occur in Europe and North and South America, but the tropical and subtropical waters of South and East Asia and the Pacific are the main foci of these public health hazards. The other beach-linked diseases, however, are common to all crowded beaches, especially those exposed to nearby sewage discharges. Successful breaking of the faecal-oral transmission route must include the control of sewage and pathogen discharges to coastal waters or, in the short term, restrictions on the use of polluted beaches and in the consumption of contaminated seafood. Much remains to be done in this respect, particularly in the densely populated developing countries bordering the tropical and sub-tropical seas.

sive diffusion, and is rapidly eliminated. Long-lived ocean fish have high levels of mercury in muscle, but fish in enclosed seas or coastal waters may have residues up to a thousand times higher. These high muscle concentrations are predominantly of natural origin, as a consequence of net accumulation through a long life history. There is no evidence that these accumulated residues have produced any effect on fish.

246. Predators of fish, such as sea birds and mammals, accumulate organic (methyl) mercury in tissues to exceed those of fish, those feeding inshore having higher levels than those feeding in open oceans. There is little evidence that high tissue concentrations (in livers or feathers of seabirds) are damaging, possibly because of an associated and antagonistic uptake of selenium. However, declining numbers of fish-eating ospreys and sea eagles have been associated with tissue levels of up to 50 ppm.

247. At Minamata, Japan, mercury poisoning from the consumption (20-50 $\mu g\ d^{-1}$) of locally contaminated seafood caused 2,000 cases of intoxication between 1930 and 1968, with 43 deaths recorded from 1953. That disaster led to the adoption of recommended international limits for levels of mercury intake in the diet (0.3 $\mu g\ wk^{-1}$ of total mercury) and for seafood concentrations.

248. There is disputed evidence of accumulation of cadmium in marine waters through the food chain, although it is evidently taken up by phytoplankton. Zooplankton and filter feeders dependent on phytoplankton have body burdens of a few ppm but some oceanic fish have only 0.03 ppm (dry). Although cadmium is not considered an essential element, concentrations up to 100 $\mu g\ l^{-1}$ have enhanced phytoplankton growth in laboratory experiments. No effects are reported for algae, molluscs and crustaceans with levels of 0.4 $\mu g\ l^{-1}$ in sea water. These "no effect" levels are significantly higher than general background levels in ocean or coastal waters (about 0.001 to 0.2 $\mu g\ l^{-1}$) but may be exceeded in some inshore areas.

249. There appears to be little direct accumulation of cadmium from sediments by benthic organisms, and it is generally thought to be taken up from water. Cadmium is transferred from marine algae to molluscan herbivores and through them to predatory carnivores where it is sequestered as metallothionein (e.g. in molluscan kidney tissues, or fish liver and gills).

250. Marine organisms take up lead from sediments or inshore waters with high inorganic lead concentrations; uptake by mussels appears to be linear with time of exposure. Like cadmium, low levels of lead (800 $\mu g\ l^{-1}$), enhance growth of some phytoplankton species, possibly in response to accompanying nitrate anions; in other species no effects were found at 100 $\mu g\ l^{-1}$. Adverse (growth) effects are reported at 300 $\mu g\ l^{-1}$ for some protozoa, and 100 $\mu g\ l^{-1}$ produced total mortality of the crustacean *Gammarus locusta*. Acute mortality of molluscan embryos occurs at 500 $\mu g\ l^{-1}$ but adults are more resistant with sub-lethal effects occurring at higher concentrations. These "effect levels" are orders of magnitude higher than sea-water concentrations (less than 0.01 $\mu g\ l^{-1}$). There have been cases of lead poisoning of aquatic birds feeding in sea and fresh water

3. *Petroleum hydrocarbons*

255. Hydrocarbons from oil exploitation and use are present in the open North Sea at concentrations of 1 to 3 μg l^{-1} and at lower concentrations in the open ocean. Levels of hydrocarbons an order of magnitude higher occur close to oil platforms and in estuaries with significant shipping, offloading and refining activities. Sediments have 5 to 160 ppm, but this may rise to more than 1,000 ppm in polluted estuaries. Effects reported on living organisms near oil rigs or accident spill sites, include high tissue levels of induced enzyme activity (e.g. mixed function oxidase) in molluscs, reduced growth in sea grass, behavioural change and recruitment failure in crabs, and successional changes in small benthic crustaceans. Higher oil residues have also been reported in the livers of fish. A sea-water concentration of 50 μg l^{-1} of the aromatic fraction of oil, compared with the natural background of only 1 μg l^{-1}, would need to persist over a wide area before significantly affecting the larval stages of fish.

4. *Conclusions*

256. This brief review shows that, with the possible exception of mercury, trace metals are present in such low dissolved concentrations in ocean waters and even in most coastal waters that they do not constitute a hazard to marine organisms. The accumulation of organic mercury residues is associated with damage to fish-eating birds, and the risk of mercury poisoning of man justifies control measures to limit the dietary intake through seafood. It is not known, however, precisely how sea-water concentrations relate to mercury levels in fish. Cadmium, although included among the "black list" substances controlled by international agreement because of its possible effects on man, appears to present no hazard to marine organisms or to man via seafood. Similarly, arsenic accumulated by marine organisms appears to have no adverse effects at present levels.

257. Halogenated hydrocarbons pose a demonstrable hazard to top predators which accumulate residues in fatty tissues; the risk is more significant where such organisms are living near hot spots of contamination, such as sewage dump sites and industrial discharges. Oil, while a significant pollutant affecting amenity when present as slicks or tar balls, seems otherwise not to pose a serious hazard for marine organisms, except at the site of oil spills, or of continuous releases from refineries and at other industrial sites. However, some habitats, particularly in polar regions and in the tropics, are particularly vulnerable and in enclosed coastal waters even spills of around 100 tonnes have caused great damage to sensitive species, such as marine birds and mammals.

258. Within the marine ecosystem, many natural and man-made factors interact in a complex way. A number of approaches have been developed to provide some measure of the total effect of these conditions on biological targets. Among the physiological responses to adverse conditions are anomalies of growth, fecundity and development; biochemical indices, have also been used. The limitations, as well as the strength, of such an integrated approach need to be

spheric deposition.

263. Globally, present inputs of nutrients from rivers due to man's activities are at least as great as those from natural processes. The inputs in different localities vary widely, depending on a range of factors including population density, land use, effluent treatment, estuarine topography, dispersal rates and natural marine sources of the nutrients. In some enclosed waters and coastal seas these inputs have led to clearly detectable and sustained increases in nutrient concentrations in the water. The areas thus affected are numerous and geographically widespread but all have the common feature of limited water exchange with the open sea.

264. There is no evidence of comparable sustained increases in open-shelf waters or open-ocean areas and there seems little likelihood that this could occur with the present rate of inputs since 80 to 90 per cent of the nutrient input is taken up by primary production within estuarine and nearshore waters (see Chapter II). A significant observable effect of excessive nutrient inputs can therefore be expected inshore, and this is indeed manifest in the frequent occurrence of algal blooms and the increased biomass of benthic algae and aquatic vascular plants. Limited increases may have desirable consequences in terms of enhanced production, but large inputs will degrade the environment in a number of ways, especially if the oxygen demand of the decaying plant material from large blooms leads to hypoxia and the death of sensitive organisms with high oxygen requirement, such as fish.

265. In the Baltic Sea, systematic monitoring since 1980 has produced evidence of eutrophication, as seen in progressively decreasing oxygen concentrations and increasing levels of nutrients. Recorded biological effects over the same period indicate higher summer rates of primary production and, since 1980, of increased productivity, including that of fish, but exceptional and unwelcome blooms of plankton algae have also occurred. Although it is recognised that some events are related to climatological and hydrological variations in the Baltic, the documented increases in nutrient inputs to this enclosed sea are a matter of major concern.

266. Possibly related to higher nutrient inputs was the unusual bloom that occurred along the coasts of Denmark, Norway and Sweden in 1988. The alga responsible was the small flagellate *Chrysochromulina polylepis* which reached maximum concentrations of 50-100 million cells per litre. The bloom did great damage to seaweeds, invetebrates and fish in coastal waters between 0 and 12 m depth along a 200 km stretch, and, through an unidentified toxin, also affected farmed salmon, costing the Norwegian fishing industry over US$10 million. Although the toxin does not accumulate in fish flesh, it has been found in blue mussels (*Mytilus edulis*) but there were no reports of illnesses in man. The remarkable feature was that this species had not been recorded previously as producing large blooms in these waters and was not known to be toxic.

267. Off the Dutch coast nitrogen in sea water increased by a factor of four and phosphorus by a factor of two over the period from 1930 to 1980. In the inshore waters of the German Bight the increases were by factors of 1.7 and 1.5, respectively, over 23 years. Phytoplankton biomass increased dramatically during the same period and flagellates overtook diatoms in abundance in

272. Experience has shown that it is possible to control and reverse eutrophication by reducing discharges of nutrients and organic carbon. There are well documented cases of recovery of fishing grounds damaged by nutrients from sewage sludge after dumping has stopped. For specific point sources, it can be sufficient to discharge effluent further offshore to an area of greater water movement, since adverse enrichment is less likely if the nutrients are adequately diluted and dispersed. In areas with restricted circulation, removal or diversion of a substantial part of the nutrient load (particularly nitrogen) and its release to suitable areas should be considered. Effective techniques are available for nutrient stripping but the costs are high and, where the main source of nutrients is agriculture, major changes in farming procedures or intensity would be entailed for effective reduction of discharges.

273. In interpreting data on eutrophication and in forecasting effects, it must be recognised that the marine environment shows ill-understood short-term fluctuations and even less well-understood long-term changes due to natural causes. Moreover, it is difficult to predict effects in large geographical areas to which a variety of sources provide inputs, each of which by itself might not be significant, but which together might have a cumulative effect on extensive areas such as the New York Bight, the Baltic Sea or the coastal zone of the south eastern North Sea. However, it should be possible, at least on a local scale, to identify areas of restricted water exchange such as lagoons, inlets, fjords and enclosed bays which, if subject to enhanced nutrient input, might be expected to show adverse effects, and to afford these areas a greater degree of protection or control.

D. ECOLOGICAL EFFECTS

1. General considerations

274. Long-term effects of contaminant exposure of populations or communities are difficult to distinguish from natural changes. Reliable observations of population changes over sufficient time (decades) are largely limited to some commercial species, ocean plankton and a few inshore benthos communities. Statistical analysis of the data is not always convincing. In addition, the cause of the change is not always recognized and it needs to be supported by realistic laboratory and field experiments. This may leave a trend, even though statistically established, "looking for a cause".

275. The establishment of a relationship between a toxic agent and the frequency or intensity of effects on a target requires that the dose and the mode of exposure be defined and that this be interpreted in terms of wild populations rather than of individuals used in laboratory or field toxicity testing. The effects of exposure will vary not only between different pollutants (or mix-

characteristics. Changes in temperature, dissolved oxygen and suspended sediment loads are often significant determinants of chemical form and availability, so that biological response is modulated by interactions between contaminants and natural variables, as well as by biological factors.

282. If a population does decline, relaxation of interspecific competition leads to a changed community, in the first instance by a localised change in species dominance or loss. This will be irreversible if recruitment from adjacent populations cannot occur. The time-scale of recovery and the degree to which population changes can be reversed and species or communities restored are uncertain since they are critically dependent on the specific conditions at the damaged site, as well as on the potential for replacement. The study of these conditions along concentration gradients from point sources of a pollutant, and following accidental releases, as well as the subsequent recovery of damaged habitats and communities are of considerable practical value.

283. The difficulty of monitoring biological change, given its long-term and extensive geographic variation, and the problem of interpreting these observations in the light of the results of experimental exposures of a few species to a few known contaminants, are not easily resolved. Where changes are expected, for example in areas receiving discharges, monitoring programmes may be initiated, but they may involve an expensive and long-term commitment of resources, often unpopular with funding agencies, control authorities, and even with scientists. In addition, it is often charged that irreversible damage will ensue before the results of long-term programmes are accumulated and analysed.

284. It follows that long-term field observations seldom provide early warning of significant effects at population level, nor do they by themselves identify the principal or even important causative agents. Aside from catastrophic events, it is usually difficult to distinguish between natural and man-made causes of biological change. The careful analysis of natural phenomena (e.g. El Niño), or of changes in biological communities following accidents, or along a gradient from a pollutant source, seems to offer the best direct evidence for population response to natural events or human activities. These field investigations can be enhanced by studies of biological and chemical mechanisms and processes, and by the development of models to extrapolate relevant findings to populations. An indirect assessment may be made from the combination of (a) data on population dynamics, (b) process studies of contaminant impact, and (c) knowledge of spatial and temporal distribution of the contaminant.

285. To illustrate the problems inherent in the detection of long-term effects at low concentrations of contaminants, or where a suspected cause has not been identified, a variety of examples of biological change attributed to natural phenomena and/or to human activities is given in the following paragraphs.

Bohusland (Baltic) herring shows a periodicity of about 110 years, and alternates with that of the North Sea spring-spawning herring, all the other stocks show similar patterns of good and bad years. In the case of the North Sea herring, these reflect the periodicity of ice cover north of Iceland. Similarly timed changes in the widely separate stocks of Adriatic, Californian and Japanese sardine are considered indicative of widespread climatic change. A shorter-term cycle is that of the Peruvian anchovy, which is influenced by the oscillation of hydrographic conditions known as El Niño (see paragraph 119). This regular reduction of coastal upwelling in the eastern Pacific leads to reduced productivity and to a limited distribution of the anchovy, which remain abundant only in areas where productivity is maintained.

b. Temperature effects

289. Temperature produces significant direct and indirect effects at all levels of biological organization. Point-source discharges at higher than ambient temperature, in contrast, are almost entirely local in their effect. A long-term (25 years) study of effects on the benthic fauna adjacent to a thermal discharge from a 2,000 MW nuclear power plant (Clyde estuary, U.K.) has demonstrated fluctuations in growth and abundance of the principal macro- and meiobenthic species, attributable to both climatic and thermal effluent influences on recruitment, growth and mortality. In some years, a higher than average recruitment to the population was associated with higher than normal temperatures prior to spatfall. The fluctuations, however, appear to have had little effect on the rather stable benthic community. Another long-term analysis of recruitment of juveniles to the population of an inshore fish (sand smelt, *Atherina presbyter*) in an enclosed bay (Southampton Water) showed no change in population structure over a 12-year period of thermal discharge from a 2,000 MW fossil-fuel power plant. Thus, although strictly local and short-term effects of such point source discharges can be identified, it is difficult to distinguish natural fluctuations from those due to human activities. A world-wide warming as a result of a change in climate might, however, have more significant effects in the marine environment, e.g. by changing the extent of habitats as a result of a sea-level rise, by favouring species with higher temperature tolerance or by increasing the rate of critical physiological processes.

c. Changes in coral reefs

290. Oil spills, disruptive fishing practices, mining, development impacts and storms are obvious causes of damage to coral reefs. Changes inland (deforestation) have also been correlated with reduced coral reef cover in the Pacific, because of increased sediment load in the run-off waters, which is damaging to corals. There have also been reports of at least localized decline, with "bleaching" due to the loss of zooxanthellae from the tissues, attributed to various contaminants (e.g. the herbicide 2,4 D, oil, sewage, nutrients) but often without critical evidence or testing. A recent report argues that the loss of zooxanthellae is associated with meteorological and oceanographic events which have resulted in marked increases in surface-water temperatures in extensive areas. In this case, natural cycles of change could again be held responsible.

baseline of incidence of various diseases. This work should be encouraged.

f. Beached sea birds

296. Sea birds are exposed to contaminants in the sea through predation on contaminated marine organisms, or by direct contact with oil residues or plastic debris on the sea surface. A survey of beached sea birds is maintained in some areas to monitor the effects of man-induced hazards. In the autumn of 1969, a massive disaster affected birds in the area of the Irish Sea, with more than 12,000 birds cast up on the adjacent shores. Almost all those affected were adult guillemots (*Uria aalge*) just past the moult. Efforts were made at the time to assess the possible influence of epidemic disease, lack of food, or accumulation of pollutants. No clear conclusion could be drawn, though the effects of exposure to pollutants, including PCB residues, could not be ruled out at that time.

E. RECOVERY OF DAMAGED ECOSYSTEMS AND SPECIES

297. It is pertinent to consider the extent to which damaged habitats and species are able to recover once polluting inputs have ceased. An ecosystem damaged by oil, nutrients or sewage will typically have lower species diversity, shorter food chains and less efficient energy transfer between trophic levels than an unaffected ecosystem. The simplest expectation is that the pre-impact system will eventually be re-established. However, since ecosystems are highly dynamic, often with several possible stable states, recovery need not follow the same sequence or time scale as loss, and the system will not necessarily revert to its previous structure.

298. The effects, and also the recovery, will depend on local conditions. Wastewater discharges, even if they do not carry toxic chemicals, may still result in an overall increase of nutrients as well as in a change in their balance. For example, municipal wastewater discharge around Stockholm has greatly increased in quantity since the beginning of the century, adding in particular to the phosphorus loading of the receiving waters and resulting in heavy blooms of nitrogen-fixing blue-green algae, decreased water transparency and periods of oxygen deficiency with hydrogen sulphide generation. Between 1968 and 1973, biological and chemical purification was introduced to all sewage treatment plants in Stockholm, and, as a result the phosphorus concentration in surface water dropped from 17 to 4 $\mu g\ l^{-1}$, the frequency of occurrence of blue greens decreased, water transparency improved, oxygen content is increasing and free hydrogen sulphide is now seldom found.

299. As another example, the Thames in the U.K. was rich in fish centuries ago, but increasing sewage load and other discharges through the nineteenth century caused substantial reductions in dissolved oxygen. By the early 1950s, several miles of the tidal waterway were oxygen-deficient every summer, long stretches were without fish life, and the bottom fauna was

with the result that methyl mercury levels in pike (*Esox lucius*) dropped significantly and a ban on fishing was lifted.

303. Once the environmental dangers of DDT and PCB were discovered, their use was restricted or banned in many northern hemisphere countries in the early 1970s. Subsequently, levels in the environment dropped, for example, in areas off the Californian coast, in the Japan's Inland Sea and in the Baltic. After a few years, concentrations in living organisms also declined, and PCB levels in Baltic seals dropped by 50 per cent. Since then, however, there has been no evidence of further decrease, and adverse effects remain. In the case of DDT, total residue levels (consisting mainly of DDE) declined from the early 1970s and, by 1984, were only 10 per cent of the earlier levels. However, residue levels increased again after 1984, and the egg shells of fish-eating birds, which had begun to return to normal, have recently become thinner again. Thus, while the bans and restrictions produced an initial decrease of these synthetic organics, the downward trend has now halted, possibly because past contamination built up persistent residues in sediments, from which they are now steadily recycled.

304. The best documented record of ecosystem recovery is that from oil incidents, although the extent and speed of recovery varies considerably. In some cases large spills seem to have had only minor impacts, while in others small quantities of oil have caused considerable damage. Apart from any clean-up treatment applied, many factors are relevant, including the nature of the oil, the meteorological conditions, the season, the characteristics of the affected area, and the opportunities for recolonisation. In general, pelagic systems in the open sea are not seriously affected and recovery is a matter of weeks or a few months. The effects on subtidal communities are more extreme and recovery takes longer in intertidal areas where the oil may have been buried in the sediment and can leach out over a long period, recovery has taken decades.

305. Experience has been gained on the re-establishment of some important tropical and subtropical habitats - coral reefs, mangroves and sea-grass beds. In some cases these habitats have been destroyed by physical activities such as port developments, bridge building, or by destructive coral mining and fishing, as well as by thermal discharges and natural storm events. Corals are notably slow to recover from damage. Only a few per cent of a reef is regenerated each year and a badly damaged reef may take several decades to recover. On the other hand, some studies show up to 80 per cent recovery of mangroves in a year, and techniques have been developed for replanting, usually successful where competitive vegetation is restricted in the conditions of variable salinity and tidal height in which mangroves thrive. Sea-grass beds have also been restored within a few months by replanting, and their associated epifauna recovered within the same period. However, successful recolonization and re-establishment will occur only if the degraded environmental conditions that induced the original problem are corrected.

312. While biological data can never attain the accuracy of chemical analysis, improvements could result from the promotion and support of further collaborative studies. Some progress has already been made at both national and international level with acceptance of robust and reliable, as well as widely available, methods of sampling. Joint biological investigations which parallel to some degree the interlaboratory exercises conducted for chemical analysis, for instance the activities promoted by IOC/GEEP, should be strongly encouraged.

317. It is important to note that climate models indicate that the increase in global mean equilibrium surface temperature due to increases of CO_2 and other greenhouse gases equivalent to a doubling of the atmosphere CO_2 concentration is likely to be in the range of 1.5 to 4.5 °C, most plausibly in the lower half of this range. However, the observed increase in global mean temperature of 0.3 - 0.7 °C over the last hundred years cannot be ascribed in a rigorous manner to increasing concentration of CO_2 and other greenhouse gases, although the magnitude is within the range of predictions.

318. The global sea level is estimated to have risen some 12 cm during the twentieth century. On the basis of the observed changes since the beginning of this century, it is forecast that a global warming of 1.5 - 4.5 °C will cause the mean sea level to rise by 20 to 140 cm. The major contributing factor to such a rise would be the thermal expansion of ocean water. The range of the estimates is an indication of their uncertainties.

319. Extensive research, much of it carried out within the World Research Climate Programme (WCRP), aims to predict climate changes from natural and man-made causes over the shorter (several years) and the longer term (several decades). The research effort for the assessment of the shorter-term changes is concentrated in the tropical regions where inter-annual variations are evident in both the oceans and atmosphere, and where well-known phenomena such as El Niño have major environmental impacts. International research within the WCRP is centred on the Tropical Ocean and Global Atmosphere Programme (TOGA), which focuses on the coupled response of the large-scale atmosphere with the tropical ocean.

320. Climate prediction on decadal time scales is limited by the inability to describe and model the circulation of the world ocean on this scale. The WCRP has therefore organized the World Ocean Circulation Experiment (WOCE) to design a research programme to develop models useful for predicting climate change and to collect the data necessary to test them. In the longer term, a second goal is to find methods for monitoring the long-term changes in the ocean circulation.

321. WOCE will collect global data sets, including measurements of sea-surface temperature and altimetry; the distributions of heat; the horizontal velocity field at one deep level at least, as measured by floats; and the surface fluxes of momentum, heat and water as obtained from a number of satellite-based and *in situ* measurements combined with the analysis of atmospheric general circulation models. The programme also includes a number of experiments aimed at making it possible to characterize those processes that are important for predicting decadal climate changes. These experiments will be concentrated in the Atlantic Ocean. The WOCE Intensive Observation Period is planned for 1990-1995 and the programme is now moving towards its implementation phase.

322. The question of the uptake of anthropogenic CO_2 in the ocean has been examined by the Committee of Climate Change and the Ocean (CCCO), and a global programme has been proposed to measure the concentration of oceanic dissolved inorganic carbon, alkalinity, and/or

B. SEA-SURFACE TEMPERATURE

328. As mentioned previously, the Villach Report has predicted changes of global mean equilibrium surface temperature in the range of 1.5-4.5 °C as the result of the doubling of greenhouse gases that may take place in the next decades. It is expected that there will be wide variations of this temperature change with latitude. In particular, the amplitude of the changes in the tropics is predicted to be small with larger changes at mid-latitudes and still larger effects at the poles. In addition, it is predicted that at mid-latitudes there will be a change of the mean with an annual cycle similar to that found at present. In contrast, at the poles the summer-time temperature is expected to remain similar to that currently observed, close to the freezing point of ice, while in the winter large increases in temperature are anticipated.

329. Changes in ocean temperature as a result of this general global warming are most difficult to predict. Not only will these arise from changes in the local air temperature and radiation balance, but also from differences in the ocean circulation due to changes in the large-scale forcing of the ocean by the atmospheric winds and the surface fluxes of heat and water. Thus, the ocean circulation as well as the way it transports heat may change substantially. It is worth noting that present knowledge of the direction of the net meridional heat flux is unknown in some ocean basins. Improving knowledge in this regard is one of the main goals of WOCE but great progress towards providing reliable estimates before the end of the century is unlikely.

330. Some indication of the complexity of the expected changes in ocean climate can be seen from the results of global coupled ocean/atmosphere circulation models. These models are limited by computer power, have poor horizontal oceanic resolution and use simplified physics for a number of ill-understood processes. Even with these limitations, initial results show that, in spite of the general atmospheric warming, the ocean may actually become cooler in some high-latitude regions due to upwelling of deeper cold water.

331. Although within the next few years global climate change predictions will improve, regional climate patterns will not be forecast successfully for a long time. In contrast, robust estimates of ocean-temperature change will probably be obtained initially for regional basins, where the change will arise primarily from changes in the radiation balance and the temperature of the nearby land masses.

332. For the present, studies of the effects on the marine environment of changing ocean temperature due to the increase of greenhouse gases will be limited to the "what if" scenarios. These can be used to consider the sensitivity of the local marine environment to changes in temperature and circulation within some range of values that may not yet be well determined.

D. ENVIRONMENTAL IMPACTS

338. The uncertainty of sea level and oceanic temperature changes make assessments of the magnitude of the environmental effects highly speculative. Some potential consequences can, however, be identified.

339. Half the world's population dwells in coastal regions which are already under great demographic pressure, and exposed to pollution, flooding, land subsidence and compaction, and to the effects of upland water diversion. A rise in sea level would have its most severe effects in low-lying coastal regions, beaches and wetlands. In developed countries protection for some regions will be possible, whereas in developing countries without adequate technical and capital resources it may not be. The frequency and severity of flooding would increase, and coastal structures and port facilities would require reinforcement. A number of Pacific and Indian ocean islands with a maximum altitude of a few metres are especially vulnerable and could become uninhabitable after rises of the sea level that would hardly be noticed elsewhere.

340. Natural wetlands, of great value as nursery grounds for many commercial fish species, as habitats for wildlife, and as zones of coastal protection are already under pressure world-wide. They may be unable to extend landward and might be lost or undergo substantial changes. Salt-water intrusion would occur in some drainage and irrigation systems, groundwater, rivers and bays.

341. Marine ecosystems could be affected by increased temperatures and alterations in coastal circulation patterns, as well as by changed water stratification due to increased run-off following greater precipitation. In polar regions, pack-ice conditions could be greatly changed, leaving some areas of the Arctic ice-free. This would reduce the albedo and lead to local warming, affecting the ecosystem as a whole.

commonly adopted for the control and prevention of pollution.

346. A set of principles with an important bearing on this subject has also been elaborated by the International Commission on Radiological Protection (ICRP). These principles, which are relevant to regulating any of man's activities that may have an impact upon the environment or human health, are as follows:

- Justification. No practice should be adopted unless there exist clear net benefits to society, i.e. the overall benefits outweigh the overall detriments to the society affected. Justification applies to an entire practice (e.g. the production, use and fate of a new agricultural pesticide) and not only to individual components of that practice, such as the disposal of any waste products;

- Compliance with exposure limits. Limits of exposure to products, their raw materials and associated wastes by both employees in relevant industries and members of the public should be established and observed;

- Optimization. Exposures to the substances concerned should be kept as low as reasonably achievable, taking technical, social and economic factors into account. Thus, exposures should be reduced by technical means, or through the use of alternative options for the handling and disposal of products and wastes, so that the overall exposures resulting from the activity are as low as economically and socially justifiable. The application of this principle requires complex balancing of scientific, economic, social and political factors, but in many cases these balances can be somewhat simplified.

347. A further concept relevant to pollution is that of "sustainable development", as recently outlined in the Report of the World Commission on Environment and Development (the Brundtland Report). This approach is proposed to permit advance or expansion of human communities without detriment to the human condition. The underlying principle of sustainable development is that the exploitation of resources, the direction of investment, the orientation of technological development and institutional change should be consistent with future as well as with present needs. The profligate use of environmental resources should no longer be acceptable and action is needed to make economic growth compatible with an acceptable environment.

3. The best practicable environmental option

351. The best practicable environmental option approach is based on the view that once wastes have been produced, the environmental costs of all disposal options must be assessed before one medium, such as the sea, rather than another, such as the land, is chosen. Air, water and land options should be considered together, not separately, when solutions have to be found for the ultimate disposal of contaminants. The aim is to choose for disposal the least damaging option with the minimal overall environmental and human health impacts, taking into account relevant political, social, economic and legal circumstances.

4. Precautionary environmental protection

352. The idea that prevention is better than cure and that releases should be prevented even before evidence of damage, has been propounded for many years. This concept has been developed in the Federal Republic of Germany as the anticipatory protection, or precautionary, principle ("Vorsorgeprinzip"). It was introduced internationally at the First International Conference on the Protection of the North Sea in 1984 and it was accepted at the Second Conference, in 1987, as a principle for the implementation of environmental legislation concerning the protection of the North Sea ecosystem.

353. The precautionary principle argues that every effort should be made to relieve the potential burdens on the environment resulting from the input of foreign substances. It is part of a policy of risk prevention aiming to reduce progressively the emission levels of all substances introduced by man into the atmosphere, water and soil. On the basis of this principle, rigorous control of contaminants has been applied by the Federal Republic of Germany in certain areas, despite the lack of evidence that environmental deterioration was linked to releases, rather than to other factors, such as natural changes.

354. Anticipatory environmental protection, as it is evolving, raises an essential issue: are the actions for the protection of the environment, taken on the basis of our present knowledge, sufficient, or do we have to assume that the future holds risks which are beyond our knowledge and therefore need to be taken into account in our current pollution prevention strategies?

and these costs are often hidden. Since the cost of achieving complete prevention of pollution ("zero discharge") will generally exceed the perceived benefits, then some level of pollution is often accepted as a reasonable compromise. However, it is difficult to compare benefits and costs on an objective quantitative basis, even when there is knowledge of the extent, severity and time scale of impacts of human activities. Further, the balance accepted by society differs among nations, regions and interests.

359. Ideally, the aim would be for a universal catalogue of costs of potential pollutants, and for an inventory of all pollution-generating activities as well as of the value of the benefits derived from them. However, there are only estimates of some costs in some circumstances, and somewhat subjective views of the benefits. The long-term, widespread effects in the marine environment are not always evident, and this has led to the still not uncommon practice of using it as a "free" service with no defined limit to its capacity to accept wastes.

360. To limit that practice, incentives for reduced pollution inputs, or improvements in pollution control can be applied through many schemes - such as taxes, fines, permits or subsidies. However, these can be administratively unwieldy. Alternatively, a specific technique of pollution abatement may be prescribed, with the objective of conforming to emission standards. This policy, however, may be too rigid or inappropriate in some cases, and thus costly in relation to expected benefits.

361. The economic analysis of marine pollution problems is still in its infancy. The cost of damage to health and resources from episodic events is difficult to estimate, although progress has been made in, for instance, working out compensation for certain oil spills such as that of the Amoco Cadiz. While crude estimates for some corrective measures have been obtained, the assessment of the costs of continued pollution, is even more difficult. Thus, the cost of the work to achieve recovery and protection of the Po river basin, which is responsible for the major part of the pollution load of the Adriatic Sea, has been estimated at over US$ 2 billion during a four-year period. Crude estimates have also been made for the cost of constructing sewage treatment and disposal facilities for the 132 million inhabitants of the Mediterranean coastal settlements that lack such facilities; these amount to approximately US$ 18 billion or about US$ 150 *per caput*. The figures would need substantial increase to cover the costs of providing the sewerage without which treatment and disposal would not be possible.

362. These are among the still few instances of cost estimates available. Given the magnitude of the sums involved, better estimates based on sound economics are needed. These should not only make it possible to evaluate direct costs, as in the two cases above, or to award compensation, as in the case of accidents. They should also provide the basis for deriving equitable systems of incentives, taxation and disincentives that may play a part in ensuring that pollution of the sea is kept within acceptable limits.

366. These conventions attempt to control the releases of substances to the sea on the basis of the hazards they pose to the environment and to human health. The International Convention for the Prevention of Pollution from Ships, 1973, and the Protocol of 1978 related thereto (MARPOL 73/78), in its regulations for the prevention of pollution by oil (MARPOL 73/78, Annex I) refer to a list of oils appended to the regulations. With regard to the control of pollution by noxious liquid substances in bulk, the Convention (MARPOL 73/78, Annex II) relies on several lists of chemicals transported at sea which have been allocated to different pollution categories (and therefore are subject to different legal requirements) based on their hazardous properties. A long-standing GESAMP working group sponsored by IMO and UNEP classifies annually the chemicals carried by ships in terms of bioaccumulation and tainting, damage to living resources, hazard to human health by oral intake, skin and eye contact or inhalation, and reduction of amenity. These hazard profiles are used by IMO in determining carriage requirements for noxious liquid substances.

367. The dumping conventions categorize substances into "black" and "grey" lists. Black list substances are those which are either simultaneously toxic, persistent and bioaccumulated, or, while essentially non-toxic, are persistent and float or remain suspended in the water where they may interfere with legitimate uses of the sea. These substances are controlled stringently and cannot be dumped in the sea in anything other than trace quantities. Grey list substances exhibit some but not all of the hazardous characteristics of those in the black list, and may be disposed of in the marine environment with special care.

2. *The Law of the Sea*

368. In 1982, the United Nations Convention on the Law of the Sea was adopted. Its provisions on the protection and preservation of the marine environment established an overall framework of governing principles and general obligations - notably those requiring States to take all necessary measures to prevent, reduce and control marine pollution from any source, and to co-operate, on global and regional bases, as appropriate, in the formulation and elaboration of international rules, standards and recommended practices and procedures and in the establishment of appropriate scientific criteria for these purposes. The obligation to co-operate also extends to the notification of imminent or actual damage, the adoption of contingency plans against pollution, and the carrying out of research programmes.

369. The Convention lays down the basic jurisdictional regime for the adoption and enforcement of laws and regulations. For pollution from ships, global rules and standards must be applied. For ocean dumping and for marine pollution via the atmosphere, States are urged to establish and apply both global and regional rules. For sea-bed activities (within national jurisdiction), States are required to adopt laws and regulations no less effective than international rules and standards, and urged to harmonize their policies at the appropriate regional level. For land-based sources, States are required to take account of internationally agreed rules and standards,

374. Thus, apart from the North East Atlantic and the Baltic Sea (both administered by the relevant Commissions), only two regional seas in the UNEP Regional Seas Programme are protected by dumping protocols: the Mediterranean and the South Pacific. This is certainly because the London Dumping Convention is considered adequate for controlling and regulating waste disposal in the various regions. However, it should be noted that the London Dumping Convention itself draws attention to the need, for States with common interests in protecting the marine environment in a given geographical area, to enter regional agreements consistent with global conventions, but also to take particular account of the characteristic features of the area.

4. Control of land-based sources

375. Action has been taken to control the input of substances from land in only a small number of regions. The Convention for the Prevention of Marine Pollution from Land-Based Sources, 1974 (Paris Convention) covering the North East Atlantic, including the North Sea, and the Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1974 (Helsinki Convention) both cover the control of substances entering their respective sea areas from land. Only two of UNEP's eight Regional Seas Conventions have been supplemented by protocols on the prevention and control of marine pollution from these sources. These are the Athens Protocol (1980) to the Barcelona Convention and the Quito Protocol (1981) to the Lima Convention.

376. The reluctance to develop and adopt legally binding instruments on the prevention and control of marine pollution from land-based sources can be understood in the light of the expected costs they would impose on industries, municipalities, and agriculture of the prospective parties, since tight control measures, standards, surveillance and monitoring systems would have to be established. This is also the reason why the establishment of a globally applicable and all-embracing convention on the protection of the marine environment from land-based sources of pollution seems unlikely, taking into account the many different stages of development in the various regions of the world.

377. All international instruments on the prevention and control of marine pollution from land-based sources take basically the same approach as the London Dumping Convention (and other dumping agreements): releases are controlled on the basis of two lists with different requirements, one more stringent than the other. However, as the conventions for the prevention of marine pollution from land-based sources deal mainly with indirect discharges to the sea, a complete banning of all discharges of substances on a "black list" would be impossible. The Paris and Helsinki Conventions are laying increasing emphasis on the control of nutrient inputs which are not included in these lists.

378. The programmes and measures set out in the conventions give the individual Contracting Parties the opportunity to fix standards governing the quality of the environment and standards for discharges. The majority of the Parties to the Paris Convention favour a policy of

384. Regarding land-based sources, very few areas are covered by relevant regional instruments and it is therefore difficult to make any meaningful evaluation of effectiveness.

385. In many cases the introduction of the control measures set out in conventions involves costs, sometimes considerable. For example, many of the provisions of MARPOL 73/78 have had substantial financial implications for the shipping industry and for administrations and industries involved in reception facilities at ports.

386. Assuming that the measures are well designed and appropriate to the environmental objectives and to the marine area in question, then their effectiveness will depend on the extent to which they are applied. Official initiatives such as the Governmental International Conference on the Protection of the North Sea, as well as pressure from the environmental interest groups, promote attitudes favourable to environmental protection and contribute to tighter control.

F. CONCLUSIONS

387. The behaviour of every individual contributes to the nature and extent of environmental damage. In meeting the objectives of pollution control, a high level of environmental awareness in the public is crucial. This can be achieved by provision of relevant information and by the establishment of educational programmes. The national agencies concerned should make research results and scientific reports, as well as data bases, available to the public, and explain them clearly.

388. Close co-operation with business interests is also necessary. Industry is well placed to know the technical possibilities for reducing and avoiding wastes and limiting the introduction of foreign substances into the environment. Its commitment to environmental protection, supported as necessary by governments through economic means such as tax incentives, investment aid and penalties, would encourage activities consistent with the health of the environment.

389. Substances introduced into the environment cross national borders in water and air and, if persistent, can spread worldwide. Therefore national measures alone are not sufficient to control them. International co-operation is needed to adopt and implement uniform measures for the prevention and control of pollution. It is the responsibility of industrialized countries to assist others in achieving these common goals. Such co-operation is being developed through the international conventions referred to above.

390. At this stage it is not possible to identify any single overall principle which, on a regulatory basis, would guide all actions to control and prevent marine pollution. Each of the many approaches used has advantages and disadvantages and, as appropriate, each should be applied within a comprehensive framework. This would cover all sources of marine pollution, the distrib-

VI. OVERVIEW

392. Broad generalisations about the state of the oceans are inevitably misleading because of their wide extent, the diversity and variability of ecosystems, the range of uses to which the seas are put, and the heterogeneity and uneven distribution in space and time of the human activities which affect the marine environment. However, in discussing those activities and their consequences, a clear distinction can be made between coastal zones and semi-enclosed seas on the one hand, and the open oceans on the other.

A. COASTAL ZONES AND SHELF SEAS

393. Man's marine-related activities tend to be focused in shallow water near the coast, and the major source of contaminants to the sea is the continental land mass. The impact of man along the edges of the ocean is therefore unambiguous, and in places substantial degradation of the environment is evident.

1. Coastal and hinterland development

394. The coastal strip, encompassing the shallow-water and intertidal area along with the immediately adjacent land, is clearly the most vulnerable as well as the most abused marine zone. Its sensitivity is directly tied to the diversity and intensity of the activities which take place there, and the threat to its future is related to the increasing concentration of the world population in this area. The consequences of coastal development are thus of the highest concern. They arise not only from the variety of contaminating inputs associated with great concentrations of people, commerce and industry, but also from the associated physical changes in natural habitats, especially salt marshes, sea-grass beds, coral reefs and mangrove forests. There is further pressure from the increasingly rapid development of mariculture around the world, both from direct contaminating inputs and from the intentional alteration of habitats to accommodate fish farms.

395. The pressures exerted directly on the coastal strip are exacerbated by activities inland. The use of rivers for waste disposal leads to consequences at the coast often far from the site of the original input, and there is a widespread need for improved treatment facilities inland, and for better control of inputs to fresh water. Also, alterations made, for a variety of reasons, to freshwater drainage systems often result in adverse changes in estuaries, for example in their

by biotoxins, sometimes with very serious consequences for human health. It is seldom possible to connect with certainty unusual algal blooms to enhanced nutrient levels, and detailed studies of some recent cases have not shown convincing cause-effect relationships. There is clearly a need for a better understanding of the dynamics of phytoplankton growth in coastal waters, and it is recommended that appropriate studies be undertaken.

399. Considering the future, it is relevant that the current anthropogenic inputs of nutrients are at least comparable to those from natural sources, and that these inputs are related to present population densities in coastal regions and their hinterland. Within the next 20 to 30 years a near doubling in human population is projected, and even greater rates of increase are expected in some coastal areas. Such changes will inevitably be accompanied by increases in agricultural and livestock production, and by further expansion of mariculture. Thus, anthropogenic inputs could become several times greater than the natural background, and the effect on coastal waters globally could then be on the scale at present found only in enclosed areas such as the Baltic and Japan's Inland Sea.

400. Given that these increases occur predominantly in developing countries where waste treatment facilities are few and population growth is most rapid, and assuming that remedial measures are not taken, then a worldwide problem is to be expected. The most severe effects will be found in areas with dense and increasing population, on coasts with restricted water circulation. Such particularly sensitive locations can be identified now. A major study should be initiated by UN agencies to estimate the scale and severity of these potential global effects, and to encourage appropriate and effective action which might include radical changes in techniques for sewage disposal and in farming practices inland.

3. *Sewage contamination*

401. While the input of human sewage to the sea is a major cause of deoxygenation and eutrophication and a source of chemical contaminants, it also introduces pathogens, posing a major health risk to consumers of seafood and to recreational users of the littoral zone. The consumption of contaminated seafood is firmly linked with serious illness, including viral hepatitis and cholera. Earlier work on the connection between bathing and disease produced conflicting or ambiguous results, but epidemiological studies have now provided unequivocal evidence that swimmers in sewage-polluted sea water have a higher incidence of gastric disorders and that the increase is correlated with *Enterococcus* counts in the water.

402. The studies further indicate increased incidence of non-gastric disorders (ear, respiratory and skin infections), but in this case there is no correlation with indicators of sewage contamination. It is clear that current health standards are not generally adequate and often are not properly enforced. Improved control and monitoring is therefore essential. Also, because conventional treatments may not in all circumstances be the best or most economic approaches for

fish species has been restricted, for example in parts of the eastern United States.

407. As a result of public concern, the manufacture and/or use of some organochlorines is banned or restricted in a number of countries. Consequently, downward trends in concentrations in sea water and in the tissues of organisms are now being recorded in some parts of the northern hemisphere, but sediments are still a major reservoir for substances like PCBs, which may be reintroduced into biological cycles when the sea-bed is disturbed. This will be a potential hazard for the foreseeable future. In some parts of the world, the use of persistent pesticides is still high, for example in countries with large cotton production.

408. Every year hundreds of new chemicals are introduced to the market, many of them with accompanying impurities such as chlorinated dioxins and dibenzofurans, while known chemicals are turned to new purposes. The unforeseen dangers of new materials or formulations are exemplified by TBT. Only when its effect on non-target organisms was discovered was its use seen to be unacceptable and action initiated to control and replace it. Some other chemicals, such as dichlorvos, an organophosphorus compound now used by fish farmers, are new contaminants in the sea and are causing concern. These chemicals, which aim at a selected target or are used in a limited location, are more easily controlled than others such as pesticides extensively applied on land. However, once a pesticide or an industrial compound is found to be environmentally dangerous and is withdrawn, it is inevitably replaced by another which may cause its own, perhaps less well known, problems. The fate and effect of chemicals introduced into the marine environment should be kept under close and continued review by a suitable international body or programme.

6. Oil

409. Except in the immediate vicinity of sources or at the site of major oil spills, oil in the sea is generally found at concentrations too low to pose a threat to marine organisms. However, oil slicks are a significant threat to diving birds, and residual tar continues to be a serious amenity problem on beaches, affecting the economy of many communities which depend on tourism.

7. Radioactivity

410. Radioactivity causes public concern, but radiation doses from artificial radioactive substances in the oceans remain extremely low, and therefore do not add significantly to the radiation background of marine organisms or man, except in a few localities where exposure may be of the same order of magnitude as that from the average natural background. However, of all contaminating discharges, radioactive effluents from peaceful uses of nuclear energy are probably those most rigorously controlled and monitored. Major nuclear accidents have resulted in contamination of agricultural and freshwater foodstuffs and of seafood. Following the Chernobyl accident there was widespread contamination throughout Europe but, because the source was lo-

B. THE OPEN OCEAN

414. The main contaminating inputs to coastal regions are river-borne. They settle out mostly in the estuaries and shallow waters, and little reaches beyond the edge of the continental shelf. In the open ocean, in contrast, the two principal sources of contaminants are shipping and the atmosphere. In addition, contaminants are contributed directly to the deep sea by abyssal tectonic activity.

415. The shipping inputs arise mainly from operational activities and from deliberate discharges. Oil is the most obvious contaminant, but biocides from antifouling paints leach into the water along shipping routes, and recently the accumulation of ship-related plastic debris has been increasing. Dumping and accidents also contribute, but much less so than in shelf waters.

416. While some of the atmospheric contribution consists of substances picked up from the sea surface and later returned to it, certain contaminants are carried by air masses from the continents. These include large amounts of desert sand and materials from volcanic activity and forest and grassland fires, as well as contaminants reaching the air from evaporation, incineration and combustion processes. There is an observable decrease in concentrations of these atmospheric contaminants as measurements are made at increasing distances from continental sources.

417. Contamination does occur in the open oceans. Uptake of mercury by long-lived fish species justifies control measures to limit human dietary intake, but most of the mercury is derived from natural sources. Another metal, lead, shows elevated ocean-water concentrations resulting from human activities, but in some areas levels are now falling with the declining use of lead in fuels. In general, metals are present at such low levels in ocean water that they are not a demonstrated hazard to marine organisms. Synthetic organic compounds are also detectable but, again, levels are too low for effects to be expected. The study of nutrient flux to the oceans shows that present anthropogenic inputs do not have any impact beyond the edge of the shelf. Oil from shipping is detectable at the surface of the open sea but mainly in the form of degraded residues, with little impact on marine life, and the reduction in oil-related traffic, combined with tighter international regulations, has reduced the extent of this problem.

418. At present, exploitation of minerals and energy in the open ocean is negligible, and only a major expansion of effort would justify concern. This may seem a far-off prospect, but developments are sensitive to commodity and energy prices, which may change quickly, so complacency is not justified. Any impact from deep-ocean mining would be most likely on the sea-bed. At present our understanding of abyssal ecology is insufficient to provide a reliable assessment of the effects of disturbance and sedimentation.

419. We conclude that in the open ocean, in contrast to coastal zones, impact from man's direct activity is slight and, while concentrations of some contaminants are enhanced, they are still low, and measurable effects are not detected. However, lead, chlorinated hydrocarbons and arti-

425. Such issues are for the most part relevant to medium- or long-term time scales, in contrast to most of those discussed so far, which are short term, affecting us now and requiring action immediately. In preparing this report, it was decided to focus on the short-term problems but, in reacting to them, to be aware of the others and to take them into consideration as and when sufficient understanding develops from current research.

D. PREVENTION AND CONTROL

426. Many activities have adverse impacts on the sea, and public awareness of the degradation of the environment is increasing, with strong attitudes emerging in favour of its protection. A concept attracting increasing support is the precautionary principle which, in its original formulation was carefully integrated as part of a national package of approaches to environmental management. This principle proposes action even in situations where damage has not been demonstrated, in order to safeguard against possible future risks. However, especially for waste disposal, it is essential to take a balanced view after consideration of all the options, including the banning of waste-producing activities. It must be recognized that prevention of pollution in one sector of the environment could transfer it to another where the consequences could be more severe or less predictable.

427. Thus, in comparing the relative advantages of land or sea disposal, the possibilities and implications of, for example, contaminating ground water with sewage must be weighed against the expected impact of disposal to the marine environment. Reviewing the options involves more than just selecting the appropriate environmental sector to receive the wastes - atmosphere, land, fresh water or the sea; there are also issues of storage or destruction; containment or dispersion; use of accessible or remote sites. In the longer term, improved waste management, with emphasis on waste reduction, will make a significant contribution to the prevention of pollution in all sectors of the environment. Obviously, cost considerations must also be relevant in reaching decisions, and an economic assessment should be part of any process leading to them.

428. It is important for example to see how the costs of damage relate to the costs of action to minimize or avoid pollution. Advances have been made in the techniques for analysis of costs incurred as a result of marine pollution and in the evaluation of the benefits of control and abatement. Inevitably, however, the values attributed to a potentially polluting activity and the cost of preventing or cleaning up after it must reflect local conditions and values.

429. In addition, the difference in approaches and languages of natural sciences and economics may lead to misunderstandings or even to misguided decisions. Initiatives are therefore needed to improve communication and understanding, so that both disciplines can be directed to the common aim of safeguarding the marine environment.

APPENDIX A

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APPENDIX B

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APPENDIX C

ANNEXES TO THE REPORT

I.	R. ARNAUDO	THE PROBLEM OF PERSISTENT PLASTICS AND MARINE DEBRIS IN THE OCEANS
II.	M. J. CRUICKSHANK	EXPLOITATION OF NON-LIVING MARINE RESOURCES: MINERALS OTHER THAN OIL AND GAS
III.	R. M. ENGLER	DISPOSAL OF DREDGED MATERIAL
IV.	S. W. FOWLER	CONCENTRATION OF SELECTED CONTAMINANTS IN WATER, SEDIMENTS AND LIVING ORGANISMS
V.	E. D. GOLDBERG	SELECTED CONTAMINANTS: TRIBUTYLTIN AND CHLORINATED HYDROCARBON BIOCIDES
VI.	Y. HALIM	MANIPULATIONS OF HYDROLOGICAL CYCLES
VII.	INTERNATIONAL MARITIME ORGANIZATION*	INTERNATIONAL CONVENTIONS ON THE PREVENTION OF MARINE POLLUTION: CONTROL STRATEGIES
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IX.	P. S. LISS (ed.)	LAND-TO-OCEAN TRANSPORT OF CONTAMINANTS: COMPARISON OF RIVER AND ATMOSPHERIC FLUXES
X.	L. MAGOS	MARINE HEALTH HAZARDS OF ANTHROPOGENIC AND NATURAL ORIGIN
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XII.	A. D. McINTYRE	SEWAGE IN THE SEA
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XVI.	H. WINDOM	QUALITY ASSURANCE OF CONTAMINANT DATA FOR THE MARINE ENVIRONMENT

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* Office for the London Dumping Convention

APPENDIX E

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