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JOINT GROUP OF EXPERTS ON THE SCIENTIFIC ASPECTS OF MARINE POLLUTION
- GESAMP -

REPORTS AND STUDIES

No. 15

The Review of the Health of the Oceans

United Nations Educational, Scientific and Cultural Organization

Mr. A. Preston
Ministry of Agriculture, Fisheries
and Food
Fisheries Laboratory
Lowestoft
Suffolk NR33 0HT
United Kingdom

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

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

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

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

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

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

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

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

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

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

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

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

REPORTS AND STUDIES No. 15

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

The Review of the Health of the Oceans

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

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

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

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

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

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

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

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

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

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

Dr. J. Portmann
Ministry of Agriculture, Fisheries and Food
Fisheries Laboratory
Remembrance Avenue
Burnham on Crouch
Essex CM0 8HA
United Kingdom

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

NOTES

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

2. This report is available in English, French, Russian and Spanish from any of the Sponsoring Agencies.

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MEMBERS AND CORRESPONDING MEMBERS OF THE WORKING GROUP

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

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

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

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

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

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

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

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

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

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

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

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

PREFACE

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

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

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

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

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

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

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

The Working Group was given the following terms of reference:

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

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

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

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

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

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

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

ACKNOWLEDGEMENTS

The work involved in the preparation of this report has been carried out at Working Group and Task Group meetings, as well as between these meetings. Written contributions forming part of the scientific background material have been given by both nominated Working Group Members and especially invited scientists, referred to as Corresponding Members. They are all listed in the appendix without discrimination between Members and Corresponding Members. The work carried out by these colleagues is hereby gratefully acknowledged.

The first and second drafts of the report were reviewed by several GESAMP members and by several scientists not members of either GESAMP or the Working Group. This reviewing procedure is very important and the comments and encouraging support received from the reviewers are hereby acknowledged with many thanks and much appreciation. The reviewers are not identified here, but none of them is forgotten.

The large workload and great support of the editorial group, consisting of R. Chesselet, A. D. McIntyre, G. Needler, D. Schink and myself, deserves to be especially mentioned. In particular, I want to express my appreciation to Dr. A. D. McIntyre.

The administrative support of the Technical Secretaries is acknowledged. Finally, it must be mentioned that it was only through the help and support from the UNEP Regional Seas Programme Activity Centre and its secretarial staff that the work could be accomplished in the time available. This also is gratefully acknowledged.

Professor Gunnar Kullenberg
Chairman of the Working Group

Geneva, 16 April 1982

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

DIVALENT (metal)	One whose atoms are each capable of combining with two atoms of hydrogen
ENTRAIN	Carry along in the flow (of water)
EUPHOTIC ZONE	The upper level of the sea down to the limits of effective light penetration for photosynthesis
EUTROPHICATION	The process of nutrient enrichment of water which leads to enhanced organic growth but which if carried too far (hyper-trophication) causes undesirable effects
FLUSHING TIME	For sea areas, this usually refers to the time taken for the volume of water in a designated location to be replaced by water from outside; a concept which engenders high-energy discussions between physical oceanographers and engineers
GRADIENT	The rate of change of a property with respect to distance (horizontal or vertical)
HOMOLOGUE (chemical)	One of the compounds in a series which shows graded changes in structure and properties
HYDROXYLATION (chemical)	An oxidation reaction which introduces one or more hydroxyl groups into an organic compound
ISOMER	One of two or more chemical substances having the same elementary percentage composition and molecular weight, but differing in structure and therefore in properties
LIGAND	The molecule, ion, or group bound to the central atom in a chelate or a co-ordination compound
PORE WATER	Water filling the small openings and channels within rocks or sediments
PYCNOCLINE	A density gradient - see thermocline
SCAVENGING	Removing a solid, liquid or gas from a liquid or gas by its adherence to a third substance
SPECIATION (of a chemical)	Refers to the various forms in which a chemical can exist
TECTONIC	Said of rock structures which are directly attributable to earth movements involved in folding and faulting
THERMOCLINE	A temperature gradient, as in a layer of sea-water, in which the temperature decrease with depth is greater than that of the overlying and/or underlying water
UPWELLING	The process by which water rises from a deeper to a shallower depth, usually as a result of divergence of offshore currents

EXECUTIVE SUMMARY

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

1. Substances, activities, processes and effects

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

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

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

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

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

Some contaminants, such as radionuclides, halogenated hydrocarbons, and trace metals, can be detected at considerable distances from their sources, partly because of their world-wide transport by wind and ocean systems, and partly because sensitive methods are available for their detection. The controlled disposal of low-level radioactive wastes in coastal and deep ocean waters is governed by the guidelines and protection limits for the general public recommended by the International Commission on Radiological Protection (ICRP). The dumping of packaged low-level wastes is governed by the London Dumping Convention and the guidelines and recommendations of the International Atomic Energy Agency (IAEA). Compliance with the spirit and intent of these regulations should ensure that the radiation exposure to human populations does not exceed internationally recognized standards.

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

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

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

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

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

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

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

GLOSSARY

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

ADIPOSE TISSUE	A type of connective tissue specialized for storage of fat
ADSORPTION	The surface retention of solid, liquid, or gas molecules, atoms or ions by a solid or liquid as opposed to absorption, the penetration of substances into the bulk of the solid or liquid
AEROSOL	A gaseous suspension of ultramicroscopic particles of a liquid or a solid
ANOXIC	Devoid of free oxygen
ANTHROPOGENIC	Man-made
AUTHIGENIC (of a mineral)	Formed by sedimentary processes as a crystallographic unit at the place of its occurrence
BENTHIC	Of, pertaining to, or living on or in the bottom of the sea
BIOGENIC	Produced by the action of living organisms
BIOTURBATION	Disturbance of sediments by the activities of living organisms
CHELATE	A molecular structure in which a heterocyclic ring can be formed by the unshared electrons of neighbouring atoms
COMPLEXATION	Formation of a chemical compound in which part of the molecular bonding is of the co-ordinate type
CORIOLIS EFFECT	The deflection relative to the earth's surface of any object moving above the earth, caused by the Coriolis force; an object moving horizontally is deflected to the right in the northern hemisphere, to the left in the southern
DEPURATE	Become free from contaminants
DESORPTION	The process of removing a sorbed substance by the reverse of adsorption or absorption
DETRITUS	Strictly speaking, loose particles produced by wearing away of larger material but the term is often used more generally to refer to fine inorganic or organic matter suspended in the water or settled on the sea bed
DIAGENESIS	Physical and chemical changes occurring in sediments during and after their deposition but before their consolidation

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

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

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

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

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

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

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

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

On the other hand, effects can be seen in semi-enclosed seas, shelf seas and coastal zones. Semi-enclosed seas, like the Gulf of Mexico, the Mediterranean Sea, the North Sea and the Baltic Sea receive substantial contamination. In some cases the living resources have been locally contaminated to such a degree that fisheries have been stopped in limited areas, sometimes leading to suspicion among consumers that fish caught elsewhere in adjacent areas may be contaminated and thus causing problems for the marketing of fish from whole regions. In a number of local "hot spots", the ecosystem balance has been disturbed, e.g., due to eutrophication. In one area of the North Sea (the Waddensea), and in the Baltic Sea, pollution has been implicated in reducing the populations of some marine mammals.

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

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

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

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

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

3. Problems requiring further examination

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

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

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

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

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

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

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

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

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

New chemicals are continuously introduced in the commercial, industrial and medical fields, and many of these will inevitably find their way into the sea. Chemicals in present use but not previously found in the marine environment cannot be ruled out as potential contaminants of the sea. Among organic chemicals, a list of some thirty compounds or groups of compounds has been noted, and in particular phthelates, toxaphene and low molecular weight hydrocarbons can be emphasized as requiring examination.

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

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

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

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

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

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

4. Concluding remark

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

CHAPTER I

SCOPE AND PURPOSE OF THE REPORT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

New Zealand Waters

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

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

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

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

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

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

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

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

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

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

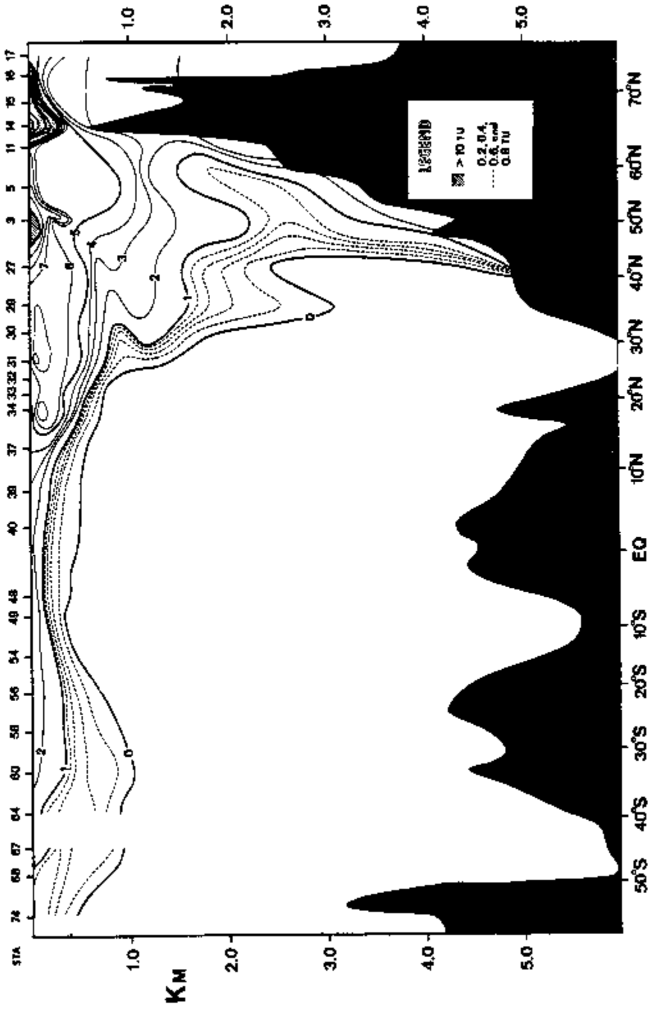

Figure II.2 : Western Atlantic tritium during GEOSECS taken from Ostlund et al. (1976)

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

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

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

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

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

The Indian Ocean

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

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

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

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

South-West Atlantic

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

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

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

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

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

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

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

The South-East Pacific Coast

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

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

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

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

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

11.5 The ocean floor

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

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

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

The Gulf of Mexico

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

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

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

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

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

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

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

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

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

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

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

West Africa

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

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

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

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

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

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

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

CHAPTER III

BIOGEOCHEMICAL CYCLES

III.1 Introduction

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

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

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

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

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

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

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

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

Mercury in the environment

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

The occurrence and use of mercury

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

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

Mercury in the atmosphere

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

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

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

Mercury in soils

Mercury concentrations in soils cover an extensive range of 10 to 15,000 ng/g; for uncontaminated soils, the mean values are between 60 and 80 ng/g. In the terrestrial environment, mercury may occur in different forms, but mostly in

The North Sea

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

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

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

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

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

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

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

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

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

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

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

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

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

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

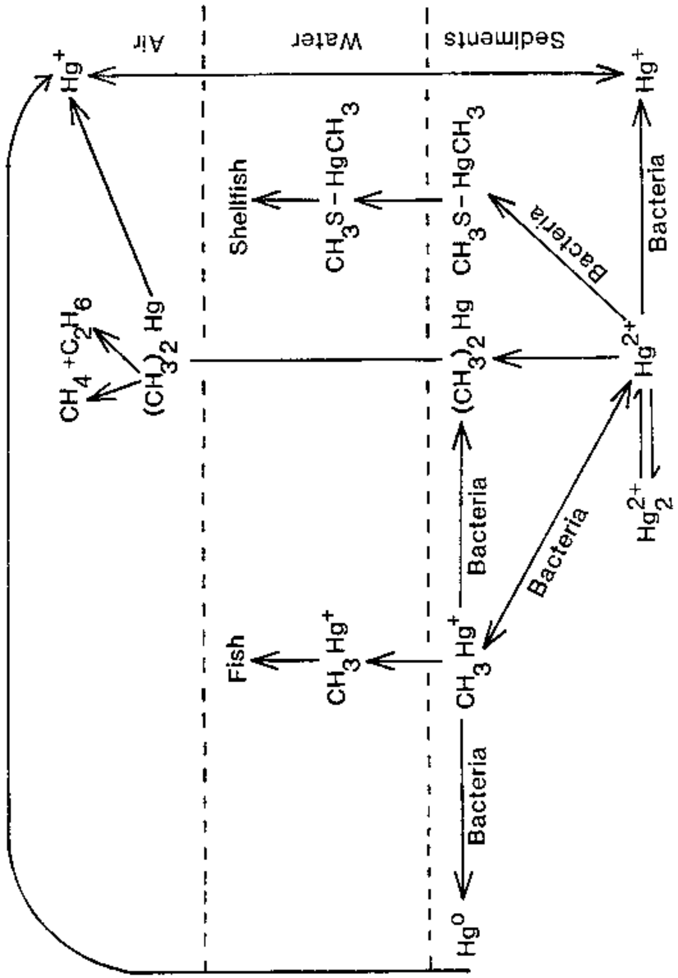

Figure III.2 : Biological cycle for mercury. Figure taken from Wood and Goldberg, 1977

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

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

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

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

CHAPTER VI

SPECIFIC PROBLEMS OF REGIONAL SIGNIFICANCE

VI.1 Introduction

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

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

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

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

VI.2 Methodology in regional studies

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

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

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

* denotes dissolved.

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

Public health threat

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

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

Sub-lethal effects

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

Aquaculture

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

Plankton blooms

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

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

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

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

Tainting

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

CHAPTER IV

POLLUTANTS IN THE MARINE ENVIRONMENT

IV.1 Introduction

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

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

IV.2 Sewage

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

Ecosystem effects: The main impact of sewage from pipelines that discharge into relatively deep or well mixed water is in the immediate vicinity of the outfall where turbidity depresses phytoplankton production, and the benthic environment is altered by sedimentation. On the periphery, the effect is usually one of enhancement of biological communities by the input of inorganic and organic nutrients. If the pipeline discharges on to the shore, growth of seaweeds and intertidal animal species adapted to high nutrient levels may be encouraged. Such enhancement of limited groups of species is one of the important effects of sewage input, which disturbs the energy transfer through food webs, eventually leading to greatly reduced species diversity. The impact can be considerable on some natural communities, such as coral reefs, or in low-nutrient habitats, where the long-established balance of species is easily upset. In general, however, treated sewage from a properly designed and well positioned outfall is unlikely to have a significant detrimental or beneficial effect over a wide radius.

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

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

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

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

Dumping

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

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

Outfalls

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

Diffuse inputs

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

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

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

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

Effects of pollution

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

Incidents

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

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

IV.3 Organochlorines

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

Polychlorinated biphenyls

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

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

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

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

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

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

Discussion

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

IV.4 Petroleum

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

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

CHAPTER V

USES OF THE MARINE ENVIRONMENT IN RELATION TO POLLUTION

V.1 Introduction

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

V.2. Exploitation of living resources

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

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

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

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

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

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

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

Ecosystem effects: Marine organisms absorb oil, but there is little convincing evidence of accumulation or biomagnification. In general, organisms from higher trophic levels show lower concentrations of hydrocarbons. Effects on the ecosystem include those arising from toxicity and from smothering and clogging. Lethal effects and habitat destruction may have long-term ecological impact but, except perhaps in some bird species, whole populations are seldom at risk. Assessment of environmental effects is based on observations of numbers and species of organisms killed or obviously damaged by oil discharges, coupled with laboratory measurements of toxicity through bioassays. Toxicity is largely associated with the aromatic-hydrocarbon content of the oil, although for some organisms the non-hydrocarbon components are most toxic. In addition to their acute toxic effects on marine life, crude and refined oils affect marine organisms at concentrations that do not result immediately in death. Included in these chronic effects are interference with feeding and reproduction, abnormal growth and behaviour, susceptibility to predation, and interference with chemical communication between animals and with the chemical senses used in migration. These effects can lead to changes in the abundance and distribution of individual species and to shifts in evaluate the extent of the shift in the total exposure towards or above the threshold for cancer caused by marine produce. These considerations can help to set any PNAH levels above which a fishery should be closed and which must be regained by depuration in the field or under transferred stock-holding conditions before such produce could again be made available for consumption. Medical consultants in the field of experimental carcinogenesis should review the evidence and prepare evaluations and conclusions, recognizing that the necessary experimental data, such as histopathological and detailed chemical analysis and their correlations, are only now becoming available. Such a task must include a decision as to which "indicator" PNAH compound, or spectrum of compounds, should be measured, and by which methods, in a sample of produce suspected of contamination. This leads to the important consideration of the relationship of oil "taint" to PNAH levels in tissues. Taint in itself may be a reason for rejection of produce but its presence or absence is not necessarily an indication of the PNAH levels. The concentration of selected carcinogenic PNAH compounds or assemblages must be determined by direct analysis. These levels should form the basis for closure or re-opening of a fishery or the release for consumption of marine produce that has been affected by oil pollution, but which has subsequently been transferred to cleaner waters.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

IV.5 Metals

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

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

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

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

Many industries release trace metals into the environment, which can reach the sea through a variety of routes. Generally, trace metals are discharged together with other wastes such as sewage, detergents and other inorganics. Interaction with these other wastes and the various components of the sea-water alters the original physico-chemical forms of the trace metals. In most cases it is difficult to determine the individual physico-chemical forms separately, but these forms largely determine the fate of the metal in the environment. For example, particulate forms are more readily accumulated by filter-feeding organisms and are taken out of the water column more quickly. Trace metals complexed by detergents and other organics contained in sewage are much less absorbed than metals in ionic form. On the other hand, metal alkyls such as methyl and ethyl mercury are more extensively absorbed by biota than inorganic mercury.

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

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

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

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

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

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

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

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

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

IV.6 Radionuclides

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

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