Intergovernmental Oceanographic Commission technical series

7

Comprehensive outline of the scope of the Long-term and expanded programme of oceanic exploration and research

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PREFACE

This text is published in the IOC Technical Series in accordance with Resolution VI-I of the Sixth Session of the Commission, and Recommendation 11.1 of its Bureau and Consultative Council. It has also been given a more limited distribution as an Annex to the Report of the Sixth Session of the Commission - which approved the Comprehensive Outline of the Scope of a Long-Term and Expanded Programme of Oceanic Exploration and Research (LEPOR) as a basis for further development of the programme - and as document E/4759 of the Economic and Social Council of the United Nations. The Twenty-Fourth Session of the United Nations, to which the Comprehensive Outline had been forwarded by the Chairman of the Commission in compliance with its previous resolution 2414 (XXIII), recorded its appreciation in resolution 2560 (XXIV), 9 January 1970. Intergovernmental organs of certain co-operating Specialized Agencies have also examined the Comprehensive Outline.

In Resolution 2560 the General Assembly also:

"Reaffirms its conviction that any exploration or research carried out under the Long-Term and Expanded Programme will be exclusively scientific in nature and that all such activities falling under the national jurisdiction of a State shall be subject to the previous consent of such State, in accordance with international law;

Requests the United Nations Educational, Scientific and Cultural Organization and its Intergovernmental Oceanographic Commission to keep that programme up to date and consider its implementation in appropriate stages, in co-operation with other interested organizations, in particular the United Nations, the Food and Agriculture Organization of the United Nations, the World Meteorological Organization and the Inter-Governmental Maritime Consultative Organization;

Urges Member States to co-operate with the Intergovernmental Oceanographic Commission in the implementation of that programme in appropriate stages;

Commends the close working relations that have developed between the Intergovernmental Oceanographic Commission and the United Nations, the Food and Agriculture Organization of the United Nations, the World Meteorological Organization and the Inter-Governmental Maritime Consultative Organization, including the establishment of the Intersecretariat Committee on Scientific Programmes relating to Oceanography which consists of representatives of the latter organizations, to further, in consultation with the Chairman of the Intergovernmental Oceanographic Commission, the common aspects of the work of the Intergovernmental Oceanographic Commission and those organizations;

Requests the Intergovernmental Oceanographic Commission and the organizations mentioned above to continue to work closely together for the furtherance of their common objectives, within their own terms of reference;

Requests the Secretary-General to report to the Economic and Social Council on the progress made in the updating and implementation of that programme."

In November 1969 the IOC Secretariat circularized all Member States, and other organizations concerned, seeking further information concerning their preparedness to participate in the LEPOR, and the availability of scientists, research craft and other facilities. Responses continue to arrive at the Office of the Commission. They are being analysed by the Secretariat, which now includes staff members of FAO and WMO as well as of Unesco under arrangements between organizations participating in the Intersecretariat Committee on Scientific Programmes relating to Oceanography which was formed in 1968 mainly to co-ordinate the necessary broader support for the Commission by organizations of the United Nations system and the use of the Commission, as appropriate, as an instrument to forward their own programmes in marine science.

The information and suggestions received will be taken into account by a Group of Experts on Long-Term Scientific Policy and Planning, the establishment of which was decided by the Commission at its Sixth Session. This Group of Experts is composed of up to 24 scientists, acting in their personal capacity, selected from among lists of nominations presented by Member States and by the three scientific advisory bodies of the Commission - the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions (ICSU); the Advisory Committee on Marine Resources Research (ACMRR) of FAO; and the Advisory Committee on Oceanic Meteorological Research (ACOMR) of WMO. In the selection process account is taken of the need both for broad and appropriate geographic participation, and for scientific expertise covering so far as practicable the entire broad scope of LEPOR.

The Group of Experts, which is to keep under continuing review the LEPOR and advise on its implementation, will formulate proposals for decision by the Bureau and Consultative Council of the Commission (later, under its revised statutes, by the Executive Council).

More specifically, the Group of Experts is instructed:

1. To develop the scope and content of the Long-Term and Expanded Programme of Oceanic Exploration and Research of which the International Decade of Ocean Exploration is an important element, by

(a) keeping under review the development of relevant national and international programmes and by stimulating and assisting the discussion and elaboration of such programmes within appropriate scientific bodies;

(b) identifying fields of research requiring increased emphasis, because of their scientific importance or the economic potential of the resources to which they relate, and promoting interest in developing programmes of work in these fields.

2. To develop criteria for the assignment of priorities to various elements of the Expanded Programme, taking into account:

(a) the interests of governments and scientists in pursuing specific investigations of common interest;

(b) the urgent need for the developing countries to be able to participate in an effective way in the Expanded Programme;

(c) the availability of funds, facilities and personnel.

3. To find ways of interrelating projects which are relevant to the Expanded Programme and which are being carried out by various international and regional bodies.

The Group will meet first towards the end of 1970; representatives of ICSPRO organizations (United Nations, Unesco, FAO, WMO, IMCO) will participate. Its Chairman will present its first report to the Seventh Session of the Commission in the Spring of 1971.

The present published version will be given wide distribution also to scientific institutions and to governments of non-Member States. Comments and suggestions are invited from recipients; they will supplement information and views already solicited from Member States of the Commission, and will be useful to the Group of Experts on Long-Term Scientific Policy and Planning in its future work.

During the first half of 1970 the membership of the Commission reached 70 States and membership now includes a large proportion of States that may be expected to participate in the Long-Term and Expanded Programme. It should be clear, however, from the above summary account of the steps for further development being taken or planned by the Commission, that the present "Outline" does not yet represent agreement by governments of such States on a specific list of activities and projects within the LEPOR. It is expected that such a "list" will be agreed in one form or another during 1971. However, it needs always to be borne in mind, in this connexion, that LEPOR, like the International Decade of Ocean Exploration which, starting this year, is an important element of LEPOR, is a dynamic activity, the content of which will continually change as new scientific problems and gaps in knowledge of the ocean become identified and as States - particularly, it is hoped, developing States - increase and improve their capacities to explore and investigate it.

Lastly, it seems that it will be increasingly necessary to co-ordinate LEPOR with other international scientific programmes global in scope and concerning our planetary environment - such as those proposed for investigating the entire biosphere and for monitoring environmental pollution and for atmospheric research - and which may interact or even overlap with LEPOR.

S. J. Holt,
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TABLE OF CONTENTS

INTRODUCTION

1. The General Assembly of the United Nations in December 1968 adopted resolution 2467 (XXIII), which contains the following request to the Intergovernmental Oceanographic Commission (Part D, Section 4a):

"4. Requests the United Nations Educational, Scientific and Cultural Organization that its Intergovernmental Oceanographic Commission:

(a) Intensify its activities in the scientific field, within its terms of reference and in co-operation with other interested agencies, in particular with regard to co-ordinating the scientific aspects of a long-term and expanded programme of world-wide exploration of the oceans and their resources of which the International Decade of Ocean Exploration will be an important element, including international agency programmes, and expanded international exchange of data from national programmes, and international efforts to strengthen the research capabilities of all interested nations with particular regard to the needs of the developing countries;"

This programme will be referred to further in this document as the Expanded Programme.

2. A Special Working Group of the IOC on the Long-Term and Expanded Programme, established by the IOC Bureau and Consultative Council at its 9th Meeting, met in Paris, 16-21 June 1969, and prepared a "Draft Comprehensive Outline of the Scope of the Long-Term and Expanded Programme of Oceanic Exploration and Research" (SC/IOC-VI/7 APPENDIX). The Working Group used as the basis of its work the report "Global Ocean Research" prepared by a Joint Working Party of the Advisory Committee on Marine Resources Research of the FAO, the Scientific Committee on Oceanic Research of ICSU and the AGOR of the World Meteorological Organization and more than thirty national proposals.

3. The present "Comprehensive Outline of the Scope of the Expanded Programme" as adapted from the Draft Outline reflects comments received on the Draft Outline from Member States, the United Nations Committee on Peaceful Uses of the Sea-bed and Ocean Floor Beyond the Limits of National Jurisdiction, and other interested international organizations. The report "Global Ocean Research" is attached as an Annex. In adopting this outline, the Sixth Session of the Intergovernmental Oceanographic Commission recognized that, by the very nature of marine science, the outline cannot be exhaustive and that other programmes of equal merit may well arise during the course of the Expanded Programme.

4. The purpose of the Expanded Programme is recognized to be as follows:

"to increase knowledge of the ocean, its contents and the contents of its subsoil, and its interfaces with the land, the atmosphere and the ocean floor and to improve understanding of processes operating in or affecting the marine environment, with the goal of enhanced utilization of the ocean and its resources for the benefit of mankind".

In achieving this purpose, the Commission should take into account the needs and interests of developing countries.

5. The proposals for the Expanded Programme contained in the Draft Outline cover also the International Decade of Ocean Exploration as an important element of this Programme as defined by United Nations resolution 2467 D (XXIII). In order to understand better the relationship between these programmes, the Working Group recommended that the implementation of the Expanded Programme be started as soon as feasible after its adoption, preferably in 1970, and that the International Decade of Ocean Exploration be recognized as the acceleration phase of the Expanded Programme.

6. Various steps are under way to broaden the base of the IOC and to strengthen the co-operation

between IOC and other interested bodies of the United Nations system. The IOC Sixth Session decided that the broadened IOC, in close co-operation with other interested bodies, accept the proposed responsibilities to (a) develop the scientific content and form of the Expanded Programme, and (b) to co-ordinate its implementation.

7. During the early years of the Expanded Programme, major emphasis must be given to detailed planning. Although it is not now possible to identify all the ongoing and scheduled activities relevant to the purposes of the Expanded Programme, there are certain activities that can clearly contribute to its initial phases, such as:

(a) co-operative investigations, such as that under way in the Kuroshio and adjacent regions, and those planned or projected in the Caribbean, Mediterranean, Southern Ocean and North Atlantic;

(b) those elements of IGOSS that relate to the research on the scales and frequencies of oceanic phenomena, investigations of ocean-atmosphere interaction directed towards understanding of the ocean, and studies of variability required for the design of the eventual operating system;

(c) those elements of World Weather Watch and the Global Atmospheric Research Programme that concern oceanic phenomena and the influence on them of atmospheric conditions and processes;

(d) those elements of the regular and field programmes of international agencies dealing with scientific aspects of marine resources and their environment.

8. It was recognized that a number of co-operative investigations are being carried out by international organizations outside the United Nations system, such as ICES and ICNAF. Such investigations may be highly relevant to the purpose of the Expanded Programme and ways must be found to facilitate their co-ordination with programmes being implemented within the United Nations system. For example, an IOC/ICES/ICNAF Co-ordinating Group for the North Atlantic has already been established with this end in view.

It was also noted that a number of supporting activities within the United Nations system and by other organizations will contribute importantly to implementation of the Expanded Programme. These include activities related to data and information management; training, education and manpower; instrumentation and methods; technology and supporting facilities and services; assistance to developing countries; legal aspects of scientific investigation. Comment on these matters is given later in this document.

9. During the development of the Expanded Programme, new co-operative projects will be presented for possible inclusion. In the view of the IOC Sixth Session, the following criteria could be applied as appropriate in the selection of co-operative projects:

(a) Member States are willing to participate actively in the project;

(b) the project can be carried out most effectively through international co-operative action;

(c) the project has a sound scientific basis and is well designed to yield significant new information;

(d) the project will provide information and understanding that will contribute to the goal of enhanced utilization of the ocean and its resources;

(e) the project will help meet the needs of developing countries.

A project that satisfied all these criteria would be an extremely strong candidate for inclusion in the Expanded Programme. It will not be necessary in each case that all criteria be met, but the willingness of Member States to participate is clearly essential.

PART I

SCIENTIFIC CONTENT OF THE EXPANDED PROGRAMME

1. PROBLEMS OF OCEAN-ATMOSPHERE INTERACTION, OCEAN CIRCULATION, VARIABILITY AND TSUNAMIS

Introduction

The ocean and the atmosphere are two parts of a vast thermal engine with a common source of energy, solar radiation. The two parts interact strongly and continuously with each other. Progress in many problems in oceanography and in meteorology is largely dependent upon close collaboration between oceanographers and meteorologists. For example, the transfer of heat, water and momentum between the earth's surface (over 70 per cent of the area being water) and the overlying atmosphere constitutes one of the major problems concerning the structure and behaviour of the ocean and the atmosphere.

This transfer has as components motions so small that they cannot be resolved by any foreseeable observation network; nor could they be analysed adequately by any foreseeable computer. Their magnitudes and properties must be expressed in terms of "average" values of atmospheric and oceanic parameters. In various ocean-atmosphere projects considerable effort is being applied to the measurement at isolated points and using elaborate instruments and equipment, of the fluxes of heat, water and momentum. Methods are also being sought for expressing these fluxes in terms of the larger scale parameters.

In research into problems of such complexity, simplification is generally an essential preliminary if progress is to be achieved. A major aim must be the development of an ocean-atmosphere model of global application. But first the feasibility of such models must be assessed and for this purpose it is best to choose problems which permit simplifying assumptions in order to develop and test the quantitative and predictive worth of comparatively simple numerical techniques. Such steps are valuable not only for theoretical work. Whenever possible they should be tried as an essential part of the planning of any large-scale observational programme.

The development of ocean-atmosphere models must be a joint effort on the part of meteorologists and oceanographers. The weather systems which are generated and maintained by the fluxes of heat, water and momentum will affect the temperature structure of the ocean through the generation of turbulence and of currents in the sea. In turn, the air-sea interaction processes will be affected by changes in the temperature structure of the ocean. In some way or other all these changes must be taken into account in numerical models. Thus the air-sea interface is of importance to both meteorologist and oceanographer and must be considered in studies of any large-scale aspects of the ocean or the atmosphere.

The horizontal and vertical movements of ocean waters are among the most striking manifestations of dynamic and heat interaction in the ocean and a most important link in the chain of its internal energy and matter exchange. Oceanic circulation serves to redistribute the heat and substance of the ocean between the various latitudes and depths and is thus a source of enormous reserves of heat. Similarly the large amount of heat released by the ocean to the atmosphere at high latitudes through freezing of the uppermost layers of the ocean, and the modifying effect of the ice cover on the weather in these regions, are of great importance in the overall heat exchange balance.

Of particular importance is the investigation of frontal processes and frontal zones in the ocean, and of the associated upwelling and sinking phenomena. The frontal zones are also of interest because of the associated biological activity.

Study of many aspects of the variability of the oceanic environment depends on the results of research on ocean water circulation. The variability of the environment in time and space has a bearing on the dynamics of marine ecosystems. Knowledge of the short-term and long-term variability of physical characteristics are important for forecasting weather conditions. Investigation of the internal waves and tides in the open ocean is also important since in a number of areas they determine the dynamics and intermingling of the waters.

The tsunami is among the most disastrous of ocean phenomena. Originating in areas where underwater earthquakes and volcanic eruptions occur and spreading over the ocean for many thousands of miles, this sea wave or series of waves ("tsunami"), marked by low-frequency oscillation, possesses enormous energy. In the open ocean the tsunami is rarely noticeable; but at the coastline its height may reach 35 metres under certain conditions. The tsunami occurs most frequently in the Pacific Ocean, but is also to be observed in other oceans.

A. Ocean-atmosphere interaction

Project 1.1: Small-scale ocean-atmosphere interaction studies

Programme outline - The programme includes investigation of the adjacent boundary layers of the ocean and the atmosphere and of their structure in relation to waves, heat, water and chemical elements exchange, including a closer study of oceanic turbulence and turbulent exchange of momentum and heat at all pertinent scales, the exchange of chemical elements such as halogens and carbondioxide as affected by turbulence and breaking waves, as well as departures from geostrophic approximation at different levels within those layers. Small-scale vertical gradient measurements with modern methods in both the ocean and the atmosphere should be made and examined in relation to larger-scale distributions and phenomena. Wind effect on the sea surface should be studied further. Multi-ship operations of various patterns, using arrays of buoys and masts, would be needed for these purposes. Upper-ocean data should be expenditiously exchanged. These investigations should be conducted in different regions. They are of particular interest in the equatorial and tropical regions where more stable winds and currents predominate.

In addition, instrumental measurements of wind waves will be organized to obtain wave spectra which represent the kind of data which has multiple uses, e.g. in ship-designing. Such data should include two-dimensional wave spectra and statistical information on wave steepness. Consideration should also be given to the possibility of analysing in spectral form wave data from trawlers and also to the possibility of improving techniques of visual observations including those made on breaking waves and cross seas.

Project 1.2: Investigations of the heat and water exchange through the ocean-atmosphere interface (medium scale)

Programme outline - The enormous accumulation of heat in the surface waters in low latitudes and its effect upon the formation of tropical storms should be a subject of special interest. Otherwise, detailed studies of the heat exchange through the surface are important in all areas for estimating the total heat budget of the ocean. Studies of thermo-haline structure would permit correlation between the heat exchange through the ocean surface and the peculiarity of the deeper water circulation.

Project 1.3: Larger-scale ocean-atmosphere interaction studies from storm surges to the coupling of quasi-permanent baric centres of the atmosphere with the major features of the oceanic circulation

Programme outline - Studies of storm surges and and development of prediction methods will require improved sea-level measurements (cf. also Project 1.16) and the establishment of files of compatible atmospheric and oceanic data. Such files covering entire oceans will permit important correlations between major dynamical features of the atmosphere and the ocean. The development of IGOSS (cf. Section 5) will contribute greatly to these large-scale studies.

Project 1.4: Special study of scales and frequencies involved in ocean-atmosphere interaction

Programme outline - Numerous studies require a monitoring network. No network can be effectively designed without knowledge of the scales and frequencies of fluctuations of environmental characteristics, including wind and current velocity. Pilot studies are underway in some fields and should be extended to others. The same studies will contribute to the investigation of oceanic variability as such (cf. Project 1.14) and will allow determination of the required accuracy of measurements in the ocean as related to the scales of phenomena.

B. Water circulation and distribution of properties in the ocean

Ocean circulation redistributes heat and other properties between different latitudes and depths. Upwellings, which bring rich reserves of nutrients to the surface of the ocean, are parts of the general circulation which affect the biological productivity in a most radical way.

Little can be studied in the ocean without thorough knowledge of the circulation. So far, the general circulation of the world ocean is understood in a gross way. Knowledge of details is very uneven. Not only the major currents, but the less clearly defined and the less permanent features, need to be examined further.

Among the various projects suggested the most important are the following:

Project 1.5: Studies of mixing, and diffusion, both vertical and horizontal, at all pertinent scales, and of the processes which cause them such as surface effects, turbulence, internal waves, convection, overturning, etc. The degree or intensity of overturning in connexion with winter cooling should be studied thoroughly.

Programme outline - Special observations and measurements will be required, of the type described under Projects 1.1 and 1.4. The orientation of the programme and the methods of data treatment would be different. The results obtained will be applicable in Projects 1.7 to 1.12.

Project 1.6: Detailed investigations of the zonal flows recently discovered in middle and low latitudes.

Programme outline - Arrays of buoys with current meters and sections repeated synchronously by several ships would constitute the backbone of such investigations. Important planning and co-ordination experience can be drawn from the EQUALANT expeditions conducted by the IOC during 1963-1964.

Project 1.7: Investigation of the processes converting surface water into intermediate, deep, and bottom water, of the rates of such conversion, and of the subsequent return path of these waters to the surface, including further transformation involved and particularly problems of underflows beneath eastern and western boundary currents.

Programme outline - These investigations would be planned and conducted in accordance with the methodology developed for each specific case. Use of modern instrumentation, such as STDs or continuous chemical analysers, may be particularly desirable. In some areas research submarines may provide a means of conducting observations and measurements under ice.

Project 1.8: Studies of budgets of water, heat, salt and nutrients in various ocean basins.

Programme outline - Depending upon the size of each specific basin and the character of the water exchange with neighbouring basins (through straits, passages, shallow areas, etc.) detailed surveys of physical and chemical properties would be designed to last shorter or longer periods of time. In certain cases the use of fast or continuously recording devices would be strongly recommended (e.g. STDs, expendable BTs, underwater cables or buoys with continuously recording sensors).

Project 1.9: Studies of coastal and oceanic upwellings and their relation to the general ocean circulation, large-scale ocean-atmosphere interaction, and local atmosphere and oceanic conditions.

Programme outline - Studies of the immediate mechanisms of upwelling could be correlated with large-scale oceanic and atmospheric pehnomena, i.e. zonal sub-tropical flows in the ocean and sub-tropical anticyclones. In addition, it seems probable that variations in sea surface temperature produced by changes in upwelling have important effects on the weather conditions in the littoral areas. Studies of such effects would be a valuable by-product of research on the upwelling process. There is also considerable geological interest in the sedimentology of such regions of high organic productivity and of the accumulation of organic matter and phosphorites. Great benefit to fisheries would result from an improved understanding, leading to prediction techniques, of the intensity and fluctuations of upwellings. Theoretical models can be developed to arrive eventually at prediction methods.

Project 1.10: Investigation of frontal systems and convergence zones, their formation and variation, and their effect on living organisms.

Programme outline - The same approach as in Project 1.9 should be followed and studied conducted in close correlation with the studies of large-scale atmospheric phenomena through detailed field surveys and theoretical models. Permanent or semi-permanent monitoring systems would be instrumental in following time variations.

Project 1.11: Investigation of the vertical structure of oceanic currents.

Programme outline - Velocity structure in some of the major oceanic currents has been examined but much still remains to be learned. The structure of slower and less regular currents has received less attention and should be examined, as should particulars of deep flows near the bottom, including the velocity structure between the bottom frictional layer.

Project 1.12: Investigation of the chemical composition of sea water and use of chemical knowledge for studying the ocean circulation.

Programme outline - Further studies on the composition of sea water and its variability in time and in space may reveal additional information on the formation, mixing, circulation and "residence time" of water masses at the surface or in the depths of the ocean. Knowledge of distribution of nutrient salts is indispensable for biological studies. There is still much to be learned from studies of salinity, dissolved oxygen, carbon dioxide, phosphorus, nitrogen and silicone. More recently, deuterium, tritium, oxygen isotopes, and Carbon 14, as well as other radio nucleides and some trace elements, less affected by biological processes, have become recognized as having prospective rôles as tracers of circulation.

Project 1.13: Studies of special problems of coastlines and estuaries: runoff, exchange with land, sediment transport, wave erosion, etc.

Programme outline - Coastal interactions with the marine environment are of growing concern to many nations since they have both direct and indirect effects on many coastal residents. These studies, because of their nature, will require complex multidisciplinary teams of scientists, including physicists, chemists, sedimentologists, coastal engineers and sanitary engineers. The results of these studies will have practical application in coastal protection, harbour construction, pollution prevention, etc.

Project 1.14: Prediction of physical processes in the sea by means of hydrodynamic-numerical methods.

Programme outline - These studies are aimed at the determination of currents, water levels, mass transports, density distribution in ocean basins or whole oceans under the influence of external and internal forces. Sufficient computer capacity and information on initial or marginal data are needed as well as the possibility of verification by a suitable network of ocean stations.

C. Variability, tsunami and tides

Project 1.15: Investigation of variability of environmental characteristics in time and in space at all scales.

Programme outline - It was traditional in the past to think of the ocean as being in a quasi-steady stage, considering even the seasonal variations as minor and limited to surface water. Now we find that we cannot progress in our study of the ocean without taking into account the variations which take place in it as a result of static and dynamic instabilities and a generally transient state of oceanic processes. Understanding of short period and long period variability of the oceanic characteristics, particularly the temperature, is important for estimating and forecasting thermal conditions of the ocean. Large-scale variations of oceanic conditions (particularly thermal) lead often to disastrous effects on living organisms, to their mass mortality or migration. The well-known El Nino near the Peruvian coast can serve as an example of such natural disasters. The total area of sea-ice cover which radically reduces the heat exchange through the ocean atmosphere interface is subject to large-scale variation from year to year. The following topics may be chosen when planning research in variability:

(a) large-scale and long-term changes in surface conditions that take place in such areas as the North Pacific and the North Atlantic require more detailed and longer series of observations in order to be understood;

(b) significant seasonal changes, such as those occurring under the influence of monsoons, as well as less pronounced seasonal changes in other regions, should be studied;

(c) small-scale and short-term variations, such as internal waves, should be investigated;

(d) seasonal and annual changes of sea-ice cover should be monitored.

Project 1.16: Further studies of tsunami.

Programme outline - A different kind of variability is involved in natural disasters which occur as a result of underwater earthquakes. The latter produce a wave or a series of waves travelling great distances and producing rapid changes of sea level which in turn result in floods and destruction. This phenomenon is called tsunami. The disastrous effects of tsunamis on many coastal areas of the world have directed the attention of many people to the study of this phenomenon. The International Tsunami Warning System was established in the Pacific Ocean recently with the assistance of IOC. Further studies of the dynamics of the formation and propagation of tsunami waves are necessary. International exchange of all tsunami data is desirable.

Project 1.17: Further expansion and improvement of the global tide station network and its extension into the open ocean.

Programme outline - More sea level recordings over longer periods of time and in many additional localities are needed in order to improve tidal prediction and tsunami warnings (cf. also Project 1.15). International co-operation can be instrumental in extending the global network of the tide gauges into the open ocean where recordings are particularly needed, through co-operative development, production and maintenance of deep sea tide gauges to be placed on the ocean floor.

2. LIVING RESOURCES AND THEIR RELATIONS WITH THE MARINE ENVIRONMENT

The scientific problems

Life probably originated in the ocean. Study of the immense variety of species now living in it throws light on the evolution of life on earth and its constantly changing composition. Investigation of the complex web of interrelations between these marine organisms and between them and the medium in which they live is a major part of ecological research. Through such research man hopes to understand, to control and to turn to his own advantage the general biological processes which give the face of earth its special character.

Probably man's oldest, and certainly still his most compelling concern with marine life is, however, as a resource of protein-rich food and food supplements for himself and his domestic animals and also for sport and as providing useful or attractive materials and drugs. He now extracts nearly 60 million tons of such products annually. Each year the food harvest is increased, as is the variety of products. Through the application of science and technology, and sufficient and wise investment, the harvest could be doubled, perhaps quadrupled, in the next few decades. This growth will be limited by the productive capacity of the sea for organisms of the kinds presently harvested. If uses can be found for the even more abundant, but smaller, animals and plants, and means devised for gathering and processing such "unconventional resources" efficiently and cheaply, the useful harvest could be increased many-fold, though by precisely how much more we do not yet know.

Future expansion of fisheries is, however, beset with economic, legal and technical problems, the solution of which will require appreciation and understanding of the population dynamics of the living resources, of their relations with the environment, and of the nature and behaviour of the organisms as individuals and as groups. Catches of many species tend to be highly variable and as yet largely unpredictable. The numbers and movements of young, and of animals of catchable size, are deeply influenced by large and small-scale features of the ocean circulation; these influences must be understood if reliable forecasting systems are to be developed and catching operations made more efficient and sure. To find, aggregate and catch the animals we must understand their behavioural characteristics, and marry biology with engineering for the invention of better methods. Fishing itself affects greatly the size and composition of stocks; management of fisheries for sustained yields requires understanding of the dynamics of the exploited stocks and of the population of organisms which nourish or compete with them. To utilize them more fully we need to know more about their biochemistry.

With the above considerations in mind, projects are outlined dealing with the environmental relationships and assessment of the living resources. The lesser known resources, particularly, would be mapped and measured, and research expanded on the dynamic processes in the ocean involved in the fixation, transfer, concentration and dispersion of organic matter and energy, and which thus determine the degree and nature of its biological productivity (Projects 2.1 to 2.5).

With one exception, this document mentions specific ocean areas only as illustrative examples. The Antarctic area is unique in that it contains the largest known unused resources, harvesting of which will require new methods of fishing and processing, as well as oceanographic studies to assist in locating concentrations, and weather and ocean forecasts for safety and efficiency of operation in a harsh environment far distant from centres of consumption. For such reasons the study of Antarctic seas is given special attention in the Expanded Programme (Project 2.6).

Changes in the marine ecosystem, and geographic exchanges, have special significance. Some of these originate in natural phenomena and others in human activities such as canal digging, dam building and shipping, as well as fishing and waste disposal (considered in another section of this document). More deliberately, man is becoming interested in manipulating the ecosystem to improve it from his point of view, but lasting success in such enterprises as transplantations and mariculture can spring only from scientific studies in depth to complement pilot experiments. Some biological communities need protection from change so that their study can provide a relatively stable basis (Projects 2.7 to 2.9).

Uncertainty as to the identity of the animals and plants in the ocean impedes progress in ecological research and can confuse predictions. Only a fraction of these is yet adequately described and classified; the status even of some otherwise quite well-known forms remains in doubt. Taxonomy, which has fallen into relative obscurity, must be revived and supported adequately (Project 2.10).

Equally important is the need for improved techniques of collecting and observing marine life. To a considerable extent this can be achieved by applying technology developed for other purposes. But new techniques must be developed especially for biological and ecological research. The biologist must not only be able to go to sea, but to go down into the sea and have adequate instruments for sampling all organisms in, and measuring all parameters of, his object of study. In Project 2.12 are set out suggestions for some priorities in this respect.

A large general increase is needed in the scale of biological and related physical measurements in the world ocean. Greatest advantage must therefore be taken of existing national laboratories, "ships of opportunity", island observatories, buoys, platforms established for other purposes, aircraft, artificial satellites, submersibles, underwater habitats and other new devices. At the same time a varied range of experimental work, at sea and ashore, will need to be conducted and full advantage taken of modern data processing and analysis techniques in the construction and testing of mathematical models of the natural systems being studied.

Project and programme outlines

Project 2.1: Fill gaps in knowledge of distribution in time and space and of abundance of primary and secondary carnivores, and in particular estimate biomass, sizes and availability of exploitable animals and their potential yields in several lesser known areas of potential interest, particularly some of the principal upwelling areas and the continental slopes.

Programme outline - Conduct systematic exploratory surveys in selected regions to determine the presence and concentration of animals of fishable size. Work should be concentrated on the principal upwelling areas and some of the continental slopes which appear to be highly productive yet remain little known.

Project 2.2: Determine the abundance of organisms of each size, within each trophic level in the ecosystem, and evaluate the flow of energy and material through the various trophic levels to the pelagic and benthic communities and study the influence of variability in the environment on those processes.

Programme outline - Investigate the production at each trophic level, and especially the composition of the diets of the animals and the size distributions of organisms and their food at each level. At the same time, determine the seasonal patterns of the ecosystem. Parallel laboratory studies are needed of the reproduction rates of the algae, generation times of herbivores and carnivores and the food intake and growth efficiencies of major consumers. In particular these should be done in one or more areas in which there is little exploitation, such as the Arabian Sea, and areas with higher degrees of exploitation such as the Gulf of Guinea, Peru Current and Gulf of Thailand. Endeavour to trace energy pathways through the benthic-detritus system to the demersal populations.

Project 2.3: Study:

(a) the global distribution and seasonal variation in primary and secondary production;

(b) those herbivores and small carnivores that are found in large dense concentrations and thus may eventually be harvested.

Programme outline - Measure the radiant energy available for photosynthesis and the rate of carbon fixation throughout the world ocean, at various seasons and with accompanying environmental information. Concurrently herbivore and small carnivore biomass and production should be measured.

Project 2.4: Investigate the effects of different levels of fishing and of changes in the environment on recruitment into stocks of fish and other useful species.

Programme outline - Studies of the stock and recruitment problem, including: construction of models of processes determining year-class strength; laboratory experiments for improving these models; estimation of density-dependent mortality at sea. Studies on long-term variability have to be accompanied by environmental monitoring. Special and interacting lines of investigation include (a) the construction of models of processes which might influence year-class strength, (b) laboratory experiments concerning e.g. growth, behaviour, density and mobility of the fish larvae, and (c) estimation of density-dependent mortality at sea.

Project 2.5: Identify and investigate the physical, including the optical characteristics of the water, and biotic factors of the environment which affect the behaviour and availability of fish and other useful marine organisms.

Programme outline - Exploit information coming from the physical, biological and chemical studies under various Projects with the aim of developing time/space forecasts of occurrence of concentrations of useful organisms; and to improving efficiency of harvesting (searching, aggregating, capture). This will require the employment in the field of instruments to be developed under Project 2.13 (a), (c) and (d) and parallel observations and experiments on behaviour and reactions of organisms confined in tanks or enclosures.

Project 2.6: Determine abundance, distribution and interrelations of the principal organisms of the Southern Ocean, together with their life histories, aggregation and migration characteristics, particularly as related to the environment; lay the scientific basis for efficient and rational harvesting of such organisms.

Programme outline - Conduct a co-operative survey of the living resources of the Antarctic seas and study their environment. This work will involve basic research on the distribution of the principal organisms, their life histories and their aggregation and migration characteristics, particularly as related to the environmental conditions. Consideration should be given to the planning and initiating of broadly based international efforts in support of existing interdisciplinary programmes in the fields of meteorology, hydrography, biology, geology and other sciences.

Project 2.7: Study the impact upon ecosystems of natural and man-made faunistic and floristic exchanges between one sea area and another.

Programme outline - Establish biological collecting and sampling schemes at stations strategically located in relation to regions (a) of natural exchanges and (b) where man is affecting or may soon significantly affect the environment through engineering works, transportations or transplantation, e.g. at both ends of important straits and sea canals and off mouths of major rivers, the outflows from which are modified by dam systems.

Project 2.8: Study the high biological production of coastal waters, estuaries, lagoons, mangrove areas and coral reefs, particularly in view of their potential for mariculture and algal harvesting.

Programme outline - Identify on the basis of environmental characteristics and survey, potential coastal aquaculture areas on a world-wide basis and select suitable species for culture, with a view to optimum utilization and improvement of the living resources, such as fish, molluscs, crustaceans and algae. Investigation should be made of the optimum conditions for culture of these organisms.

Project 2.9: Study the desirability and feasibility of establishing marine reserves for protection and study of natural marine communities.

Programme outline - Examine the scientific criteria and practical problems of selecting marine areas which contain representative communities and within which human activities would be restricted to observation and research.

Project 2.10: It is essential that there be no uncertainty about the identity of the organisms to be exploited or investigated, and it is necessary therefore to improve capabilities for classifying, identifying and cataloguing them.

Programme outline - Take steps to encourage the pursuit of taxonomic studies which are essential as support for ecologically-oriented biological projects. Encourage biologists to engage in this field and facilitate world-wide collaboration between specialists and pooling of their efforts in using both conventional and modern techniques. Extend also the network of biological sorting centres and establish regional international collections. Improve and apply rearing techniques for identification of eggs and larvae. Assist through providing adequate means for publication of taxonomic and systematic work.

Project 2.11: Identify those marine plants and animals which are aggregated in sufficient abundance for commerical exploitation in order to use a wider range of marine organisms as sources of a greater variety of useful products.

Programme outline - Determine for each of those species its chemical composition (with special reference to toxicological and pharmacological components), its seasonal and regional variability and its ecological determinants.

Project 2.12: Investigations of dissolved organic matters and detritus and the remineralization of organic substances in the water and sediment.

Programme outline - The concentration of different organic substances in the sea waters and in the sediment must be measured. The quantity of suspended detrital organic matters must be examined to evaluate its possible usefulness as a food supply for the pelagic and demersal organisms including fish. Studies of heterotrophic organisms and their metabolic activities are needed, and these studies must be carried out not only in the sea, but also in the laboratory to clarify the reactions involved in the different decomposition processes.

Project 2.13: Develop new or improved, and preferably standardized methods, instruments and facilities for various purposes. Such developments are required in almost every aspect of marine biology. The following may serve as examples:

Programme outline

(a) to increase the ability of scientists to make direct observations, in all parts of the marine environment by providing guidelines in technology through formulation of the specific requirements of biologists for underwater study by using habitats and submersibles and by diving;

(b) to measure the input of organic material to the sea-bed;
(c) to detect and assess fish and other organisms. In particular devise methods for the detection and estimation of (i) flatfish, shrimps and other animals living on the sea-bed, and (ii) pelagic fish and squid, and perhaps also shrimps, living over continental slopes;
(d) to observe the behaviour of individuals and groups of fishes and other organisms, including their reactions to instruments and equipment operating in the marine environment; study possible adaptation and application of new techniques and the use of large observation tanks;
(e) to improve methods of sampling and measurement of the biomass and rate of production of marine organisms by application and adaptation of the most recent methods and techniques;
(f) to improve the processing and exchange of biological data by identifying those data which can be exchanged through data centres and by developing methods for handling data which at present do not lend themselves to routine exchange.

3. MARINE POLLUTION

Nature of the problem

The world ocean is receiving in increasing amounts and variety waste substances and energy from our civilization, but it does not have an unlimited capacity to absorb them. The levels reached by some pollutants in some parts of the ocean are already a matter of deep public and scientific concern, and dangerously high levels may be imminent with respect to others. Pollution affects many of man's economic and cultural activities in the marine environment. Noxious materials can be transported by physical and biological processes over vast distances from the site of their injection into the environment. Some pollutants stay a long time in the sea water and in marine organisms before they reach the sediments or decompose. Others, instead of being dispersed, may accumulate in certain organisms, including those of economic interest to man. Some pollutants, or certain concentrations of them, have acute and quickly noticeable effects on the biota; others have delayed or sub-lethal effects which are not immediately apparent but may nevertheless be very important in the longer run.

There is a degree of control over the injection of some pollutants into the ocean but some reach it accidentally and others are released indiscriminately. Many pollutants reach the ocean from many sources: rivers and coasts, particularly urban and industrial effluents; the atmosphere; ships and equipment operating in the marine environment including underwater operations. Losses or impairment of use through contamination may only be prevented by rational policies based on research and monitoring. An effective monitoring programme could also deter pollution of one ocean area as a result of activities elsewhere. All the sources of pollutants mentioned above need to be monitored and eventually, as far as possible, controlled. At the same time the complex effects of each type of pollutant require detailed investigation. This involves study of their fates in the ocean environment, the selection and investigation of marine test organisms, the development and standardization of techniques of analysis and the establishment of the relevant material budget of the ocean. In some cases, wastes may be treated or disposed of in such a way as to cause benefit rather than harm. Even general scientific benefits can come from the study of pollution; thus, certain contaminants can, in principle, be used to elucidate the routes and rates of energy flow through the ecosystem (see especially living resources Project No. 2.2).

In view of the expected growth of the problem of pollution with the rise in human populations and increase in their industrial activities, and because of the broadly interdisciplinary nature of the scientific investigations required, the projects relating to this question are gathered in this document under a single heading. For the purpose of the Expanded Programme, marine pollution should be defined 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, hazard to human health, hindrance to marine activities including fishing, impairing of quality for use of sea water and reduction of amenities.

Scientific studies under the following projects should lead to the preparation of periodic comprehensive reports on the health of the ocean. These would review the state of the ocean and its marine resources as regards pollution, and forecast long-term trends to assist governments individually and collectively to take the steps required to counteract its effect.

Projects

3.1 Study of changes in the marine environment with a view to understanding the effects of known pollutants and identifying presently unrecognized ones.

3.2 Study the impact of such changes on marine life, including studies on toxicity and accumulation of pollutants.

3.3 Investigate the delayed and sub-lethal effects of pollutants on growth, reproduction, and other biological processes. Such effects, unlike, for example, mass mortalities of fish, are not always immediately apparent. Nevertheless, they are among the most serious results of marine pollution.

3.4 Development of relevant physical, chemical, physico-chemical and radio-chemical methods of analysis with special consideration to the presently-known pollutants.

3.5 Identification of a spectrum of species that are affected by pollutants in various ways and hence can be used as sensitive indicators of the level of pollution in a given area.

3.6 Standardization and intercalibration of methods of sampling analysis and of instrumentation.

3.7 Establishment of a world-wide system of monitoring of the constituents of marine pollution including the collection of samples from various environments and biota, their submission and analysis at analytical centres, the transmission of the results of analyses to oceanographic data centres and the evaluation, interpretation and publication of these results on a regular basis. Implementation of the monitoring programme has important legal aspects which are related to the problems of prevention and control of marine pollution; these urgently require study and solution by the competent organizations.

3.8 Review the sources of marine pollution and investigate the mechanism through which the pollutants reach the marine environment.

3.9 Investigate the fate of pollutants in the marine environment. This involves study of the physical, chemical and biological processes of transport, accumulation, dispersion and degradation of pollutant substances and energy.

3.10 Provide the scientific basis for devising methods of removing pollutants from the sea, of countering their deleterious effects or, where possible, of exploiting beneficial effects of these substances.

3.11 Study positive and negative effects on sea organisms by thermal waste water.

4. GEOLOGY, GEOPHYSICS AND MINERAL RESOURCES BENEATH THE SEA

Introduction

An understanding of the character and evolution of the earth's crust beneath the ocean is proving to be the key to global geology and heralds a new approach to the solution of geological problems on the continents as well as below the sea. This understanding can provide a basic scientific framework within which prediction, evaluation and exploitation of material benefits from the sea floor can be made. These benefits will be greatly diminished, if only haphazard exploration and empirical studies guide our programme.

Undoubtedly in the future the rich mineral deposits located on and beneath the sea floor will be exploited as an important source of industrial raw materials for the whole of mankind. Deposits of ferro-manganese concretions, also containing cobalt, nickel, copper and other metals, and deposits of rock-phosphate, have already been identified. Judging from preliminary data, oil deposits may also be found deep in the sedimentary formations beyond the limits of the continental shelf. However, our knowledge of the ocean's mineral resources is still far from adequate, and prolonged study both of their geographic distribution and of the concentration of the various mineral resources will be required in order to determine which of them can be profitably exploited for the benefit of mankind.

The sedimentary sequence reflects the ocean's present and its past history. It is here that we can follow the processes of erosion and sedimentation and discover the comparative rate at which deposits have formed in different regions of the ocean. Here, too, we find clues as to the original nature of the material deposited and the transformation it has since undergone. Study of this sequence will reveal the processes of the formation and distribution of many mineral deposits.

There are, in many places on the ocean floor outcrops of the underlying igneous rock. A knowledge of the relationship between the properties of these rocks and their geological framework and age will enable us to determine the nature of volcanic phenomena, the changes which have taken place through geologic time in the composition of the earth-mantle, the age and composition of the sub-oceanic earth-crust and the mechanism of metamorphic processes within the crust. This, in turn, will provide us with a better understanding of the rocks located on and below the ocean floor, their mineral potential such as chromite and nickel, and enable us to answer a number of questions relating to the geological history of our planet.

However, new theories require testing, modification and elaboration. The broad divisions of scientific problems listed below do no more than categorize some of the detailed problems to which scientists will turn their attention. The list of research programmes which follows is considered to contain the most important to be pursued in the light of presently available methods and those that can be foreseen to be possible. But as the Expanded Programme proceeds, new developments both in techniques and knowledge will necessarily lead to modified research programmes.

Principal scientific problems

A. Description, origin and dynamics of the crust and mantle in the oceans, including marginal seas, mediterranean seas and continental margins, and knowledge of the deep sources of material and energy for tectonic processes.

A.1 Fine structure of the crust and upper mantle of the mid-ocean ridges, both active and ancient, and their associated stress patterns (e.g. related to seismicity).

A.2 Nature and origin of aseismic ridges and rises (e.g. Wyvillo Thomson Ridge, Walvis Ridge, Chile Rise).

A.3 Identification, dating and history of material composing the oceanic crust and the upper mantle beneath the "stable" ocean basins, and their lateral variability.

A.4 Comparative studies of the structure and history of stable continental margins.

A.5 The dynamic processes in areas of unstable continental and crustal plate margins (trench, trench-arc and marginal sea systems).

A.6 The possible transformation between oceanic and continental crust in the marginal and mediterranean seas.

A.7 Vertical and horizontal movements of the oceanic crust and continental margins.

A.8 Processes and patterns of vulcanism.

B. Sedimentary processes in coastal regions, on continental margins and in the deep ocean.

B.1 Description of the nature, history, distribution and thickness of sediments on the sea floor and of the nature and distribution of suspended matter.

B.2 Sources of sedimentary material.

B.3 Dynamic processes of erosion, transportation and sedimentation in relation to environmental conditions including quantitative analysis of the energy balance, rates of sedimentation, etc.

B.4 Physical, chemical and biological interaction between the ocean and the sediments and rocks on the sea floor, a most important interdisciplinary problem.

B.5 Diagenesis and metamorphism of marine sediments.

C. Aspects of the sea floor with potential economic value.

C.1 Assessment of the mineral and fuel resources of the various types of continental margins.

C.2 Coastal and sea floor engineering (e.g. coastal erosion, sediment movement, "soil" mechanical properties, sea floor stability).

C.3 Possibilities of mineral and fuel resources of the deep sea floor, in relation to areas of different origin, development and environment.

C.4 Identification of geologic hazards in coastal areas and on the sea floor (earthquakes, rupture of sea floor by faults, earthquake-generated sea waves, etc.).

<u>Research programmes proposed to solve the principal scientific problems</u>

1. Morphological charting of the sea floor.
2. Systematic geological and geophysical surveys of continental margins.
3. Completion of magnetic survey over the world ocean.
4. Deep drilling at key sites.
5. Detailed studies near crests of the ridge-rift systems.
6. Ocean and land studies of trench-arc systems.
7. Investigation of anomalous deep ocean crustal areas.
8. Geological and geophysical studies of mediterranean and marginal seas.
9. Geotraverses across major crustal features and land-sea geologic transects in critical areas.
10. River mouth monitoring with emphasis on the nature of suspended materials and waters.
11. Meridional profiles of deep ocean sediments.
12. Manganese nodule and other mineral resource assays.

These research programmes may be categorized as major elements of five principal programmes.

I. Morphological charting of the sea floor.

<u>Scientific aspects</u>: Geological investigations require bathymetric charts at appropriate scales as base maps. Other marine disciplines use reconnaissance or detailed charts of sea floor morphology in aspects of their research.

<u>Practical aspects</u>: Base maps for offshore exploration for minerals and fuels; for bottom fisheries, or for engineering purposes. Bathymetric charts at appropriate scales are required for all aspects of mineral exploitation, fisheries, engineering construction, and other operations on or above the sea floor.

<u>Scales</u>: 1:1,000,000 for reconnaissance purposes. Preliminary charts for many regions, both shelf and deep ocean, can be made from available data. More precise charts at this scale will be required for deep ocean areas with spacing of 5-15 kms. between lines depending on complexity of the bottom morphology and on the nature and detail of the geological programme in the area. Scales of 1:250,000 or larger scale will be required in critical areas (where land-sea geological and geophysical transects are to be made).

II. Systematic geological and geophysical surveys of the continental margins.

These surveys include deep drilling and land-sea geologic transects, for the purpose of investigating the sediments, crust, and mantle of both stable and unstable continental margins. Emphasis is placed on comparative study of structure, geologic history and mineral resources.

Scientific problems include A.4, part of A.7, parts of B., C.1.

<u>Scientific aspects</u>: Better understanding of sedimentary, igneous and metamorphic crustal structures under the sea floor in the transition

regions from oceans to continents and the geophysical characteristics of the underlying mantle. Processes of sediment transport from the coast to the deep sea. Distribution of benthic organisms with depth and latitude. Pliopleistocene sea levels and eustatic and tectonic changes in sea level from evidence of relic beaches, terraces and coral reefs.

Practical aspects: Reconnaissance surveys to find location and extent of thick sedimentary basins and structures for possible oil and gas accumulations; discovery of phosphorite deposits on the outer shelf, and placer and beach deposits and other minerals on both the inner and outer shelf; delineation of rock structures with mineral and fuel resources continuing from the continent. Sediment and geochemical maps for fisheries.

Methods: Reconnaissance survey, using underway and station observations, of the entire marginal area. Additional geological and hydrographic investigations of key areas of high potential for minerals, or areas such as those having arctic, humid, arid or tropical hinterlands with and without high relief, areas off river mouths, and regions where there are prolongations of great tectonic trends from the continent to its margin. Methods should include geological and geophysical land-sea transects and in later phases should be supplemented by drill hole information.

III. Geological and geophysical investigations of the oceans

Investigations of sediments, crust, and mantle of deep ocean basins, ridge-rift systems, and trench-arc systems. Methods include deep drilling land-sea transects across trenches and arcs, and related investigations and drilling on adjacent islands.

Emphasis is on history, tectonic processes ("dynamics of ocean floor"), present phenomena of seismicity, volcanism, geomagnetism, gravity and heat flow, and mineral resources.

Scientific problems included in this programme are A.1, A.2, A.3, A.5, part of A.7, A.8, parts of B, C.3, part of C.4.

IV. Geological and geophysical investigations of small ocean basins (mediterranean and marginal seas).

Studies of sediments, crust, and mantle with emphasis on history relation to other deep oceans, possible transformation between continental and oceanic crust; and mineral resources.

Methods include land-sea transects and deep drilling.

Scientific problems included in this programme are A. 6, parts of B. and C..

V. Studies of sedimentary and geochemical processes.

Investigations in coastal regions, continental margins, and deep ocean, of the material and energy balance with respect to the coast and atmosphere; physical, chemical, and biological interactions between water column and sea floor; submarine erosion, transportation, sedimentation and diagenesis. Emphasis is on origin of surficial mineral deposits, such as placers, phosphorite and manganese nodules, and on stability of sea floor sediments ("soil" mechanical properties) and evaluation of geologic hazards.

Scientific problems included in this programme are B., and parts of A. and C..

5. THE INTEGRATED GLOBAL OCEAN STATION (IGOSS) (Programme aspects)

5.1 The system for obtaining oceanographic and meteorological observations from the ocean, available at present, cannot satisfy the current and increasing requirements for scientific knowledge about the ocean and atmosphere and their interactions, nor does the system satisfy the requirements for operational information about the current and future condition of the ocean environment and the atmosphere above it as well.

5.2 Scientific investigations are necessary to determine the interrelations and dynamic development features of the ocean and atmospheric processes. Until these determinations are made, little progress can be made to satisfy the requirements for short-term and long-term meteorological and oceanographic forecasts. Environmental forecast services are required to enhance the efficiency of sea trade and navigation, protection of life and property at sea, successfulness of maritime industries (fishing, petroleum, chemical etc.).

5.3 IGOSS, in conjunction with the World Weather Watch, will promote the further development of environmental sciences, it will aid in the improvement of ocean and weather forecasts, and will facilitate a better understanding of the ocean and atmosphere interaction processes. It will support countries in their exploitation of new regions in the ocean for the purpose of trade and increase the efficiency of agriculture in all countries from the resultant increased accuracy of weather forecasts and their application to food production.

5.4 IGOSS, which is being developed on the basis of scientific principles, includes the modern technical means for observations, radiocommunication and data processing and is intended to provide, together with WWW, the synchronous and undelayed oceanographical and meteorological information from the whole ocean. It will benefit from research proposed for the Expanded Programme, since subsequent design of the system will require understanding of the scales and frequencies of oceanic phenomena and the perfection of models for forecasting oceanic conditions.

5.5 The purpose of IGOSS, in conjunction with the World Weather Watch, guided by the requirements of oceanography, is to provide oceanographic and meteorological information that will support all interested countries in producing forecast services and conducting scientific ocean investigations.

5.6 The main planning question to be resolved during the initial stage of IGOSS is to determine the distribution and content of meteorological and oceanographical observations by fixed and mobile observing stations.

5.7 The Integrated Global Ocean Station System is arranged exclusively for peaceful purposes and is based on the principle of voluntary participation of the interested States. IGOSS is a world system consisting of national facilities and services co-ordinated by the Intergovernmental Oceanographic Commission, in close collaboration with WMO, with the support of all interested organizations.

6. INTERNATIONAL INVESTIGATIONS IN SPECIFIC REGIONS

6.1 International co-operation in studying systematically selected oceanic regions is of great importance. The extreme rapidity of time variations of the oceanic environmental characteristics requires rapid repeated surveys of oceanic conditions, which surveys cannot produce satisfactory data if conducted by a single vessel. In order to understand properly all physical, chemical and biological processes which take place in a particular region, their interrelation and interdependence, regular multiship synoptic surveys over the whole area of the region under investigation are necessary. Networks of buoys or other platforms may be indispensable when high degree resolution in space is required.

6.2 No country, however rich or developed economically, can provide the necessary number of research vessels and other means for such investigations. Only through international co-operation is it possible to concentrate in one region of the ocean such number of research vessels and other means as would meet adequately the requirements of synoptic or quasi-synoptic coverage.

6.3 The Intergovernmental Oceanographic Commission has already acquired great experience in organizing and conducting large-scale international expeditions: in the Indian Ocean, in the equatorial part of the Atlantic Ocean, and in the Kuroshio region of the Pacific. The Commission also planned or projected further international investigations in the Northern Atlantic, in the Mediterranean, in the Caribbean Sea and adjacent regions, and in Antarctic waters (Southern Ocean). The continuation of these co-operative investigations will be the first step of the Long-Term and Expanded Programme.

6.4 A great many oceanic regions are still poorly known. Among them are the southern parts of the Atlantic, Pacific and Arctic Oceans, including some regions bordered by developing countries. Regions where more or less satisfactory data have been collected in the past require additional detailed investigations. It is appropriate, therefore, that, during the next five years, the large-scale international expeditions planned or projected by the Commission be complemented by detailed co-operative investigations of regional character aimed at assisting developing countries by studying their adjacent waters for the purpose of national fisheries development.

6.5 Plans for these regional investigations should be developed in close collaboration with the existing regional organizations, such as ICES,* ICNAF,** etc., which have accumulated valuable experience in organizing co-operative investigations in their respective regions with great benefit for fisheries development there.

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* ICES - International Council for the Exploration of the Sea.

** ICNAF - International Commission for the North West Atlantic Fisheries.

PART II

PRACTICAL PROBLEMS OF IMPLEMENTATION

1. TRAINING, EDUCATION AND MANPOWER REQUIREMENTS

Development and implementation of the Expanded Programme will require a considerable strengthening of scientific and technical manpower. Such problems are of considerable importance particularly to the developing countries. Problems and approaches include the following:

increased reference to marine problems in natural science and engineering curricula;

development and strengthening of specialized curricula at the university and post-graduate levels;

more effective exchange of information on educational and training opportunities;

preparation and distribution of manuals, textbooks and other teaching materials in various languages;

organization of training courses for scientific, technical and auxiliary staff;

expansion and more effective use of fellowships for professional study;

arrangements for exchanges of teachers and investigators between countries;

strengthening of existing centres for training and research and establishment of additional centres.

The following actions should be taken particularly for the benefit of the developing countries.

(a) The IOC Working Group on Training and Education should develop further plans to meet training, education and manpower requirements for the Expanded Programme.

(b) Unesco, FAO and other appropriate organizations should further strengthen and co-ordinate their fellowships and training programmes in marine sciences.

(c) Member States should improve the opportunities for training and for employment of trained people in marine sciences, and should give increased support to international organizations involved in programmes of education and training, including shipboard training programmes.

2. DATA AND INFORMATION MANAGEMENT

Data and information will be one of the most important products of the Expanded Programme. Existing international systems for information and data management are not adequate to cope with the present flow of information and data. The lack of ready access to pertinent information and data presents particular difficulties to the growth of marine research in developing countries. The significant increase in the level of ocean research activity which will result from implementation of the Expanded Programme will overload these systems from the beginning. Problems that require solving include the following:

improvement and consolidation of bibliographic and related information services;

early exchange of plans and preliminary results of observational programmes;

integration of real-time exchange of oceanographic data with the meteorological system;

development of methods for storage and retrieval of biological, geological and geophysical data;

automation of international data banks and improved programmes and methods for making their contents available;

development of standardized and/or computer-compatible data formats;

timely establishment of improvement of international inventories of ocean data and samples and provision for centralized cataloguing of sea data available from various private and public sources;

strengthening system of sorting centres for biological material.

The following actions should be taken.

(a) The IOC Working Group on Oceanographic Data Exchange in collaboration with WMO, FAO and other interested organizations such as ICES should examine the above problems and take requisite steps to meet the needs of the Expanded Programme. Certain aspects of this work can be assisted by the IOC advisory bodies.

(b) Unesco, FAO and ICSU in collaboration with other interested organizations such as ICES should devote increased attention to the improvement of scientific information systems in the field of marine sciences.

(c) Member States should give increased support to national, regional and world data centres as required for the expansion and improvement of their services.

(d) Specific mechanisms should be sought for accelerating the flow of data through international exchange channels. And all meaningful data and information resulting from projects and programmes of the Expanded Programme should be considered as Declared National Programmes (DNP) or their equivalent, to be exchanged or available for exchange and subject to inventories.

3. INSTRUMENTATION AND METHODS

The Expanded Programme will require the development and availability of instruments and methods of high precision and reliability. In order for data from various sources to be pooled and processed automatically, the instruments must be intercalibrated or standardized where possible and methods must be compatible. The following problems require solution:

there is little effective intercalibration of measurements made by one Member State, with any other Member State;

information on the performance of instruments and related equipment is not readily available to Member States;

standards information to ensure high quality data is not available to Member States;

information on appropriate facilities needed for the calibration of instruments is not available;

no effective mechanism exists for standardizing on those instruments which are worthy of such a designation.

The following actions should be taken.

(a) IOC, Unesco, FAO, WMO, SCOR, ACMRR, ICES and other interested bodies should jointly intensify their support for methodological work and for the improvement, intercalibration and standardization of instruments and methods.

(b) Member States should provide increased assistance in the conduct and publication of pertinent methodological investigations and encourage the production and adoption of standardized instrumentation where practical.

(c) Member States should designate, where possible, an existing laboratory of facility that can act as a centre for information relative to that State's activities in oceanographic measurement and for the co-ordination of instrument improvement, calibration, and standardization with other Member States.

4. TECHNOLOGY AND SUPPORTING FACILITIES

The investigation and exploration of the ocean and its resources require significant technological advances as well as the expansion and improvement of facilities. The development of such technology and facilities will require considerable investments at the national level.

The following actions should be taken.

(a) Member States should encourage the development of advanced technologies for investigation and exploration of the ocean, which should be made generally available. In particular, the development should be encouraged of systems technology at all levels, providing for development of such systems as oceanographic buoys, research submersibles, instrumented spacecraft and aircraft, off-shore structures and undersea habitats.

(b) IOC and other interested international bodies should facilitate the dissemination of information on advanced technology.

(c) Member States should increase the availability of adequate facilities of all kinds for investigation and exploration activities in the oceans. In this connexion appropriate assistance should also be provided to developing countries through bilateral and multilateral programmes including activities of Unesco, FAO, WMO, United Nations and other international organizations financed by UNDP and other international sources.

5. SUPPORTING SERVICES

The Expanded Programme will require the widespread availability of precise navigational systems, improved communications, more complete and accurate forecasts of the marine environment and the expansion of programmes of hydrographic surveys, mapping and charting. In particular, in order to solve a large number of oceanographic problems and make possible geological and geophysical research, it is indispensable to carry out world-wide bathymetric surveys as well as more detailed bathymetric investigation of high accuracy of limited specific areas.

The following actions should be taken.

(a) Member States should strengthen and improve supporting services and integrate them internationally.
(b) Member States should strengthen their efforts in the hydrographic field and co-ordinate their programmes in order to improve and increase the production of bathymetric charts at appropriate scales.
(c) The Ocean Station System (Ocean Weather Ships in North Atlantic (NAOS) and North Pacific) should be used in the Expanded Programme of Oceanic Exploration and Research as they provide unique opportunities for continuous observations of oceanographic parameters and may serve as an important step towards an Integrated Global Ocean Station System.
(d) The IOC, WMO, IMCO, IHB and other appropriate international organizations should work closely together in developing international aspects of the supporting services.

6. LEGAL ASPECTS OF SCIENTIFIC INVESTIGATION

The Commission should continue its studies pursuant to Resolution V-6 adopted at its fifth session.

7. INTEGRATED GLOBAL OCEAN STATION SYSTEM (Implementation aspects)

The Implementation of IGOSS will draw heavily on all the supporting activities related to the implementation of the Expanded Programme listed in this part of the Draft Outline, with particular emphasis on:

(a) development of appropriate technology and instrumentation, standardization and unification of instruments and methods of observations for the IGOSS programme;
(b) standardization and unification of the format for the efficient exchange of data (realtime and non-realtime) obtained through IGOSS;
(c) standardization of procedures for use of the radio-telecommunication channels;
(d) organization of the oceanographic service in an integrated fashion and patterned after the World Weather Watch.

8. ORGANIZATION FOR IMPLEMENTATION OF THE EXPANDED PROGRAMME

It was agreed that the Expanded Programme, which would consist of certain on-going and proposed activities of IOC as well as those of other organizations, represented a new magnitude of effort and would require a periodic review and co-ordination by the proposed IOC Executive Council, taking into account the views expressed by the governing bodies of the other organizations involved. For this purpose certain meetings, or portions of meetings, of the Executive Council might be designated for matters pertaining to the Expanded Programme, thus ensuring that suitable scientific and technical competence is available on national delegations for such meetings or portions of meetings.

It was agreed that the International Co-ordinators and the Chairmen of the relevant subsidiary bodies should report to the Executive Council on these occasions.

In a discussion of the co-operation among international organizations, it was reported that the Unesco Executive Board had authorized the Director-General of Unesco to establish an Inter-Secretariat Committee which would meet with the Chairman of the IOC to further common aspects of the work of the IOC and the participating agencies, to recommend to these agencies appropriate support action for the IOC and to co-ordinate such action. This Committee has been formed and met in August 1969.

There was general recognition that the United Nations should continue to use the IOC's technical competence in the scientific aspects of ocean affairs. In this connexion, the responsibilities given to the IOC in United Nations Resolution 2467 were welcomed. The IOC should continue, in co-operation with other organizations of the United Nations system, to assist the General Assembly in its consideration of matters related to the ocean.

In order to guarantee the effective participation of as many countries as possible, the possibility should be considered of bringing a number of their own national programmes within the general framework of the Expanded Programme.

It was agreed that there was a continuing improtant rôle for the scientific advisory bodies in the review and evaluation of programmes proposed and implemented during the Expanded Programme. The IOC has recognized the need to broaden the field from which scientific advice is drawn beyond that now covered by SCOR and ACMRR. In this connexion, ICSU bodies are now considering alternative ways to strengthen and consolidate scientific bodies concerned with various aspects of marine science. Some steps are also being taken to establish an ocean engineering association under the World Federation of Engineering Organizations. In response to the request of the IOC Bureau, WMO is giving further consideration to its scientific advice to the IOC in the field of meteorology.

9. ASSISTANCE TO DEVELOPING COUNTRIES

An important goal of the Expanded Programme is enhanced utilization of the ocean and its resources for the benefit of all mankind. More than seventy developing countries border the oceans. Unused fishery resources and fuel and mineral deposits are known to exist off the coasts of a number of these nations; also, many of them are dependent on maritime transport to link coastal communities and to provide the basis for foreign trade. In the past, the developing countries have had only limited opportunities to make use of the ocean and its resources; they have, therefore, a special interest in fully participating in the Expanded Programme and in applying its results to further their own development. The developing countries should also have the opportunity to participate in the development of the resources of the deep ocean to the extent possible. To aid them in their efforts to participate and to reap the benefits arising from the Expanded Programme, the developing nations may need scientific, technical and material assistance, especially in training and education, technology and facilities, as indicated in various sections of this document.

The developing countries may also require assistance in the design and organization of scientific programmes as well as in the strengthening and improvement of existing programmes. It is essential that greater attention be given to the needs and interests of these countries to enable them to be meaningful partners in the Expanded Programme.

The following actions should be taken.

(a) The IOC, through its co-operative activities, and Unesco, FAO, WMO, United Nations and other interested organizations, with the support of UNDP and other sources, should develop plans to meet the needs of developing countries arising from the Expanded Programme.
(b) Member States should participate actively in technical assistance programmes for the mutual benefit of those concerned with the ocean.
(c) The IOC should encourage work on oceanic regions of particular interest to developing countries, with due regard to any national programmes already established, and should encourage the effective association of those countries in studies of this sort. In particular, the IOC should encourage every means of enabling them to embark upon such studies themselves, by the training of specialists, the setting up or the improvement of local teams and local scientific institutes, and the development of an adequate material infrastructure.

These actions should include:

- active participation by developing countries in planning and working out practicable arrangements for the Expanded Programme;
- particular attention to providing developing countries with data and information obtained from ocean research and exploration;
- participation by developing countries in ocean research conducted by vessels of other nations;
- increased opportunities to developing countries to utilize oceanographic research facilities in developed countries;
- increased availability of fellowships to ocean scientists and engineers in developing countries;
- liberal assistance to developing countries in useful technician training programmes;
- liberal provision of management assistance and technical assistance to developing countries in the establishment of marine science and technology facilities and in improved methods.

ANNEX

GLOBAL OCEAN RESEARCH

A report prepared by the Joint Working Party
on the
Scientific Aspects of International Ocean Research,
nominated by:

Advisory Committee on Marine Resources Research
of the
Food and Agriculture Organization

Scientific Committee on Oceanic Research
of the
International Council of Scientific Unions

World Meteorological Organization
(Advisory Group on Ocean Research)

Ponza and Rome

28 April to 7 May 1969

CONTENTS

PREFACE

In 1966, the United Nations adopted a resolution (2172/XXI) concerning the need for greater knowledge of the ocean and its resources, and the acquisition of this knowledge through international cooperation. The subsequent actions by the United Nations, the Intergovernmental Oceanographic Commission of UNESCO, and by the Food and Agriculture Organization and the World Meteorological Organization, led to the following situation in mid-1968.

The Secretary General had prepared a report that recommended an expanded program of international cooperation to assist in a better understanding of the marine environment through science. Governments and appropriate organizations were encouraged to agree to broaden the base of the Intergovernmental Oceanographic Commission to enable it to formulate and coordinate such a program. The concept of an International Decade of Ocean Exploration had meanwhile been proposed.

In June 1968, the IOC Bureau took a number of steps to initiate development of the expanded program, including the inviting of its advisory bodies, SCOR and ACMRR, together with other interested scientific bodies, to consider its scientific content. Shortly thereafter, SCOR, at its Ninth General Meeting, suggested that this consideration could best be given by another working party of scientists in their individual capacities, organized jointly with the advisory bodies of FAO and WMO, as was done in 1967 in connection with UN Resolution 2172 and preparation of the report "International Ocean Affairs". At its Fifth Session (July 1968), ACMRR accepted this proposal and recommended the following terms of reference for the Joint Working Party on the Scientific Aspects of International Ocean Research:

(1) To develop the scientific content of a comprehensive program of international cooperation in exploration and research in the ocean and its resources, taking into account the survey and proposals of the UN Secretary General in connection with UN Resolution 2172, and also the report on International Ocean Affairs, the existing national and international programs of cooperation in ocean exploration and research, and other relevant programs and reports;

(2) To comment on the practical problems of implementing such a program, including priorities and timing, taking into account the likely funds, facilities and personnel required.

Establishment of the group was endorsed by the executive heads of FAO and WMO, the terms of reference were accepted, and membership was established during the following months.

The United Nations, during its 23rd General Assembly in the autumn of 1968, adopted a number of relevant resolutions, including one (2414/XXIII) that endorsed the concept of a coordinated long-term program of oceanographic research and requested the Secretary General to present a comprehensive outline of the scope of this program to the Economic and Social Council and to the General Assembly during their 1969 sessions. The Secretary General was to take into account scientific recommendations formulated by the IOC within its terms of reference and in cooperation with other appropriate organizations. In another resolution (2467D/XXIII), the concept of an International Decade of Ocean Exploration, as a component of the long-term and expanded program, was welcomed, and the IOC was requested to cooperate with the Secretary General in the preparation of the comprehensive outline of the scope of a long-term program of oceanographic research, to be presented to ECOSOC.

In February 1969, the IOC Bureau formulated the following additional questions for consideration by the Joint Working Party of ACMRR, SCOR and the WMO advisory body:

1. What are the most important oceanic research problems that should receive par-

ticular attention in the near future?

2. What types of research programs can best contribute to solving these problems?

3. In what geographic areas of the world's ocean will increased research efforts make the best contribution in solving these problems?

4. What kinds of supporting facilities, services, and manpower will be needed to carry out these programs?

5. How can ocean exploration and research best contribute to the particular needs of the developing nations?

6. How can results of the above exploration and research programs best contribute to various peaceful uses of the ocean, its floor and its resources?

7. How can increased ocean research activities by the developing countries contribute to their social and economic development?

Members of IOC were invited to submit their proposals for the long-term and expanded program; these proposals and the report of the Joint Working Party would then be considered by an IOC Working Group scheduled to meet in June. As a result of the latter meeting, it should be possible to provide the Secretary General with a progress report for consideration by ECOSOC, prior to consideration by the Sixth IOC Session in September 1969. FAO and WMO, for their part, have taken steps to ensure consideration of the working party report by the FAO Committee on Fisheries and by the WMO Executive Committee Panel on Meteorological Aspects of Ocean Affairs respectively.

The Joint Working Party met in Ponza, Italy, on 28 April to 4 May, and in Rome on 6 - 7 May 1969. A list of participants is given in Annex I. Dr. C.E. Lucas was appointed Chairman, and Professor W.S. Wooster served as rapporteur.

INTRODUCTION

The Joint Working Party was asked to consider the scientific content of a comprehensive program of international cooperation in exploration and research in the ocean and its resources, to be undertaken during the long-term and expanded program, of which the International Decade of Ocean Exploration would be an important element. The IOC Bureau, after consultation with interested governments and international organizations concerned, has proposed that the program have the following purpose:

"To increase knowledge of the ocean, its contents and the contents of its subsoil, and its interfaces with the land, the atmosphere, and the ocean floor and to improve understanding of processes operating in or affecting the marine environment, with the goal of enhanced utilization of the ocean and its resources for the benefit of mankind."

The Bureau further suggested that the program should include scientific investigations and related services, training and education, development of ocean engineering, and provision of adequate facilities. Projects could be national, regional or more broadly international, and special attention should be given to the particular interests of developing nations. The WMO Panel on Meteorological Aspects of Ocean Affairs, and the Committee on Fisheries of FAO subsequently associated themselves with these proposals.

It was not possible for the Joint Working Party to discuss all aspects of marine scientific investigation, whether intended to further understanding of the ocean or to benefit its economic utilization. In order to identify the most conspicuous problems and to reveal their interdisciplinary and international character, small discussion groups were established as follows:

1. Ocean circulation and ocean-atmosphere interactions
2. Marine biological production
3. Marine pollution
4. Dynamics of the ocean floor

Each group consisted of specialists from several disciplines, and exchanges of views among groups were encouraged. In addition, a steering committee was formed to assist in coordinating the work of the discussion groups, and to consider more general problems and the additional questions formulated by IOC.

Because the discussion groups worked separately, their separate reports are different in character. For example, specific projects are elaborated with much greater precision in one section than in another. This heteorogeneity reflects both differences in make-up of the groups and differences in the status of the scientific problems discussed. Accordingly, no attempt has been made to reduce these chapters to a common format.

In considering the scientific content of the expanded program, it was necessary to determine which bands of the total spectrum of marine research should be emphasized. Just as all parts of the world ocean are ultimately connected, all types of research, from the most individual or basic to the most collective or applied, are closely interrelated. Many kinds of research are not directly dependent on international cooperation, although they benefit from international exchanges, and mankind as a whole will benefit from knowledge of their results. Other kinds of research cannot be accomplished except with active international collaboration. It was agreed that the present study should give principal attention to investigations that particularly require international cooperation for their success, but that notice should be taken of pertinent research within individual countries. The international program can only succeed if it is built on a strong foundation of continuing research by the scientists of many nations.

It was noted that the proposed program would have application to increased understanding of our planet as well as to the development of rational programs for the utilization of the ocean and its resources. Furthermore, scientific information is also required as one basis for international agreement concerning the ocean and its utilization.

There are, of course, already a number of international programs with significant relevance to those proposed in the present report. In only a few cases has an attempt been made to identify these existing or planned programs, although obviously the development of each specific project in the expanded program must be effected in full knowledge of related activities. In some cases, such as WMO's Global Atmospheric Research Programme (GARP), the World Weather Watch (WWW), and the UNDP/FAO fishery development projects, activities proposed here will complement or support the existing projects and will be assisted by them. In other cases, such as the International Biological Program and the proposed development of a post-Upper Mantle Programme by ICSU, it is conceivable that the marine component will be an integral part of the expanded program. It will be a further task in the planning process to examine the relationship between the expanded program and other related international activities.

Given the restrictions of the study, it is necessary to keep certain limitations of the report in mind. The various projects proposed by the discussion groups should be considered as examples of investigations that could contribute to fundamental knowledge of the ocean, or could serve as a basis for more effective present or future utilization of the ocean and its resources. In some cases, interested scientists have already developed a project outline, and implementation can be envisaged in the reasonably near future. In other cases, it is still necessary to identify possible participants. In all cases, it will be necessary to bring together interested scientists and governmental authorities in order to elaborate details of a program. Because many of the proposed projects have a significant technological component, it is important to involve engineers in the further development of projects.

Geographical priorities have not been stressed. Examples given for one region may be applied elsewhere if there are interested parties who wish to work together there. It is true that some regions offer unique opportunities for a particular experiment. On the other hand, many regions or current systems are so poorly known that even a simple seasonal reconnaissance is required to permit formulation of suitable problems and projects. Some of these little-known regions are mentioned in the report, and others are equally worthy of attention.

Despite the multidisciplinary membership of the several discussion groups, it was not always possible to ensure that the relevance of one group's proposal to the problems of another group was fully recognized. In some cases, the common interests of several groups suggest that economies could be made and scientific value increased if their separate proposals could be combined. In other cases, it is conceivable that an attempt to combine projects would lead to complications and delay in their execution.

Finally, it should be noted that the proposals in the present report are the views of a small group of scientists at a particular moment in the development of marine science. These views will evole, and other scientists will contribute further ideas as plans for the expanded program develop. Although it is hoped that this report will contribute to preliminary international planning, it must be recognized that new insights and new priorities will inevitably bring changes in the expanded program as it unfolds.

OCEAN CIRCULATION AND OCEAN-ATMOSPHERE INTERACTIONS

Many uses of the sea can benefit from advances made in oceanography and meteorology. Winds in the lower atmosphere control the circulation of the upper part of the ocean and affect sea conditions that influence the operations of fishermen and other marine activities. At the same time the structure of the ocean layer above the thermocline has a direct bearing on many phenomena in the atmosphere as well as in the sea. This inter-dependence of meteorology and oceanography is already leading to extensive programs of research into problems of air-sea interaction and the interests of fishery science, agriculture, marine transportation, off-shore oil industry, coastal engineering and recreation, among others, demand that such projects should be encouraged.

A major aim must be the development of an ocean-atmosphere model of global application. However, it is necessary to assess the feasibility of such a model and for this purpose it seems advisable to begin with the development of quantitative predictive techniques on problems of more limited scope. Certain field experiments, such as the coastal upwelling or the Arabian Sea experiments, are intended to elucidate specific natural processes. Whenever possible, numerical simulation of these processes (numerical modelling) should be undertaken in advance of a large-scale observational program. This would have the objective of giving an improved understanding of the process in question and should be of considerable value in designing the observational program.

Without meaning to restrict the number of such projects in any way, we offer the following suggestions as examples of tasks which would be worthwhile.

1. A System for Exchange of Upper Ocean Data

Large amounts of synoptic data on the surface properties of the ocean, such as surface temperature, sea state, etc., are already available and are being exchanged in real time. With the development of the Integrated Global Ocean Station System (IGOSS), which will be operated in close conjunction with the World Weather Watch in accordance with arrangements issued by WMO and IOC, there will be a considerable increase in the amount of such data and, in addition, a greater variety of parameters, such as mixed layer depth, will be observed or measured. In our view steps should be taken to ensure the rapid collection and dissemination on a world-wide basis of such types of these data as are required to be exchanged in real time. By this means the data would be of immediate use in marine and meteorological operations and be readily available for research studies by members of the scientific community. The results of these studies would present the data in various digested and filtered ways and could lead to the formulation of important new problems in air-sea interaction.

When observations at a measuring point are required in real time, there must be a communication link to a parent station. From that station, data can be fed into the global meteorological telecommunications system for the necessary dissemination. Before implementing such a project, it is essential that the telecommunications requirements be carefully formulated in consultation with WMO to ensure that capacity of the system is not exceeded.

2. North and Equatorial Pacific Ocean

Several indications point towards the desirability of establishing a long-term plan for the systematic observation of the North and Equatorial Pacific Ocean. Among these indicators are:

i. the discovery of the sub-tropical counter-current;

ii. the discovery of evidence of long-term fluctuations in properties near the equator and similar fluctuations in extra tropical latitudes which are probably due to air-sea interaction;

iii. certain striking correlations between the speed of the Kuroshio and the average surface temperature in the southern half of the sub-tropical gyre;

iv. a desire on the part of oceanographers in Japan to expand their programs of ocean research beyond the area presently being studied under the Cooperative Study of the Kuroshio;

v. a need from the point of view of fisheries to study the system of high productivity characterizing the regions between the North Equatorial Current and the Equatorial Countercurrent;

vi. a desire to conduct studies of large scale air-sea interaction in tropical and subtropical sea areas in connection with the problem of the formation and behavior of tropical and extra-tropical cyclones.

a. Near surface observations

We believe that an expanded program of measurement would go far to improve understanding of the large scale, long-period fluctuations of the North Pacific ocean basin. Such a program would make use of buoys where practicable, ships of opportunity and arrangements for the measurement of surface temperatures and the collection of samples at the numerous islands which are to be found in the Pacific Ocean. Information about the important fluctuations in temperature and salinity, from the surface down to the thermocline, which occur over large areas of the Equatorial Pacific, could be much improved by arrangement with the operators of the many fishing vessels in the area. The proposals should be capable of economical implementation since they consist essentially of an extension of an existing organization which relies upon the cooperation of merchant ships and fishing fleets. Since both meteorological and oceanographic facilities are involved and since the proposals may be suitable for implementation within the scheme referred to in (1) above, WMO and IOC should develop the program in collaboration.

b. Survey of the Pacific Gyre

Systematic, routine surveys should be made of the Pacific Gyre and its circulation system in order to obtain additional data concerning the fluctuations of varying period which are known to occur. This is a major project which will need to be repeated at regular intervals and the feasibility of cooperation among a number of countries should be explored. An international meeting might be held to inquire into the practicability of such a project and to develop plans for its implementation.

c. GARP Tropical Experiment 1972-73 (approx) and Mixed Layer Experiment

The possibility should be examined of carrying out oceanographic observations during the tropical experiment which is being studied by the Joint Organizing Committee of GARP and might take place near the Marshall Islands in 1972-73 (approx.). It is considered that a combined project would yield data of the greatest value for assessing the heat budget in lower latitudes.

An experiment to account for the energy budget in the mixed ocean layer should be made to complement this meteorological study but it should be continued over a period of several years. It may be hoped that this will lead to information concerning the formation and behavior of tropical cyclones.

A proposal to study a larger surrounding area between 120°E - 180°E and 15°S - 25°N may be a very useful complement to these studies. If this is found to be practicable, every effort should be made to implement it at the time appointed for the GARP tropical experiment. This may be the only opportunity for some years.

3. Coastal Upwelling

Great benefit to fisheries would result from an improved understanding, leading to prediction techniques, of the intensity of upwelling along the eastern coasts of ocean basins. Such regions are heavily productive of fish and the upwelling is sensitive to changes in the winds. The fluctuations, at present unpredictable, have a very strong effect upon the economics of fisheries.

Regional studies of the immediate mechanisms of upwelling could be correlated with larger scale meteorological phenomena, i.e. the sub-tropical anticyclones, which will be carefully observed in programs planned in the implementation of the World Weather Watch. In addition, it seems probable that variations in sea surface temperature produced by changes in upwelling have important effects on the weather conditions in the litteral areas. Studies of such effects would be a valuable by-product of research on the upwelling process. There is also considerable geological interest in the sedimentology of such regions of high organic productivity and of the accumulation of organic matter and phosphorites.

A good general description of the California upwelling zone has been obtained during the past 20 years. However, attention must be given to the development of theoretical models for numerical computations and for this purpose a denser observing or monitoring network will be required.

Sufficient is known about the California Current for an assessment of requirements for an adequate network of moored current meters and temperature sensors. On the other hand it seems probable that the upwelling phenomenon there is somewhat more subtle and complex than in other places such as the Gulf of Panama, the Benguela Current, or the Peru Current. Therefore we think that in addition to heavy instrumentation of the California Current, further descriptive surveys from the coast to 300 km offshore of other regions of upwelling are desirable, both for their own economic importance, and because some such area may turn out to be a superior testing ground for predictive models.

From the point of view of upwelling and its influence on the fisheries of Africa and other countries the region between Gibraltar and Dakar is very important and has been comparatively neglected so far.

Two types of projects are proposed. One type is a theoretical attack on the development of predictive models using data from an area of high network density, possibly by instrumentation of the California Current. Efforts should be made to ascertain whether any group of oceanographers with adequate computer resources would be prepared to undertake this research.

The second type of project is concerned with extended investigations into upwelling and it is recommended that further upwelling investigations should be undertaken in other areas. In addition to observations at sea, maintenance of recording instruments at fixed shore locations ("docks of opportunity") is needed both in upwelling regions and elsewhere in the world. Organization of such a program might be stimulated and coordinated by IOC.

4. Arabian Sea

Of all large scale, long-period transient phenomena, the annual reverse of circulation in the Arabian Sea, associated with the southwest monsoon, is the most pronounced. The Arabian Sea is also the richest undeveloped fishing area in the world, with the possible exception of the Antarctic regions.

A well documented study of the time variations of the ocean-atmosphere environment in this region would be of the greatest value both for forecasting the onset, intensity and duration of the monsoon and to assist theoreticians in developing and verifying numerical models of the general oceanic circulation. While the monsoons of India are perhaps the most dependable climatological reversing wind system in the world, the precipitation associated with the southwest monsoon is highly variable from year to year, not only in the inception and termination of the rains but also in their intensity and frequency. Some recent evidence suggests that these variations might be associated with changes in the surface temperature of the Arabian Sea. Thus part of the problem of predicting the monsoon rains - of tremendous economic importance to Indian agriculture and probably to local fisheries - may be solved by air-sea interaction study in the Arabian Sea.

Much could be learned about this reversing circulation with modest instrumentation along the shores of Somalia and southern Arabia, and with a research vessel especially assigned to the area. It would be helpful if such a ship, maintained and funded by a consortium of nations, could be made available over a period of at least five years, particularly for the physical oceanographic studies mentioned here, but also in order that scientists living in the countries surrounding the Arabian Sea may use the facilities of the ship for interdisciplinary studies of special problems.

Successful implementation of this project, which in our opinion has a high priority, will require the early improvement of observing networks in the region, as envisaged in the World Weather Watch plan; the participation of countries surrounding the Arabian Sea along with others interested in the area; the development of a detailed plan by a multidisciplinary working group of scientists; and close association with the proposed Indian Ocean Fishery Survey.

5. South Atlantic

In the South Atlantic, the time is ripe for a study of the Brazil Current and its associated three undercurrents, using methods of study which have been applied in the currents of the Gulf Stream and of Kuroshio over the last fifteen years. We envisage one or two multiple ship surveys, to delineate the synoptic structure of the Brazil Current, to reveal the presence of meanders and eddies, and to determine more precisely the path of the current once it leaves the coast of Cape Frio. It would be desirable for countries in the region and other interested countries to contribute three ships to such study, which would last about three months. We also encourage the use of neutrally buoyant floats and current meters underneath the Brazil Current in order to determine the direction of flow at various levels, which, if classical geostrophic and water mass considerations are reliable, should reveal three reversals in direction with depth - a truly remarkable phenomenon if confirmed. The surface waters of the Brazil Current appear to be fairly isolated from the rest of the ocean water and, as they flow southwards, may yield a particularly clear-cut history of the plankton community.

This project should lead to the obtaining of information on the current pattern and thermal structure which in turn could be useful to fishermen. There are also indications that certain species of fish aggregate at physical features in the Brazil Current and that upwelling occurs at certain locations along the coast. Detailed studies are necessary to confirm this empirical knowledge. The thermal properties of these waters are also likely to play an important role in influencing weather and short period climatic changes along the Brazilian coast.

This project does not involve a large effort and should be carried out when the countries principally concerned are able to do so. A meeting should be called at an appropriate time of the countries likely to participate in order that the project may be planned.

6. International Island Observations

In the study of shorter period phenomena in the ocean, such as detailed turbulent development of the seasonal thermocline, studies of internal waves and mixing processes, dynamics of the thermocline, etc., many new and sophisticated instrumentation schemes need to be tried in the ocean. It is necessary to provide facilities in a few places where the intensive trials of such measuring techniques may open up possibilities of measuring phenomena and processes previously little understood. For example, we can anticipate intensive networks of moorings , internal wave antennae, arrays of bottom-pressure gauges, scientific acoustic ranges, etc.

Such installations will be quite expensive, and it seems to us that it would be a good policy in the case of new measuring techniques to encourage scientists to install them in a common facility, in the same limited portion of ocean water, because it seems certain that the information obtained by one system of instrumentation will be very useful in the interpretation of the results obtained from other similar installations. Thus the properties of internal waves observed on a subsurface array of temperature sensors could be independently observed on a line of pressure gauges deployed along the bottom. The value of both sets of observations would be greatly enhanced if they were made in the same locality. The more sophisticated the apparatus, the more essential this interplay of installations becomes.

A large permanently moored barge, or group of barges, moored in the ocean could serve a host of related experiments. In addition, or alternatively, a suitably located mid-ocean island could be used. Criteria for selecting of such an island include access to deep water nearby and space for large shops and other installations.

This is a difficult project to carry out on a remote island and the best course may be to try to develop the first observatory on accessible islands such as Tahiti, Bermuda or Hawaii. On the other hand, some countries may have their own plans for setting up an island observatory which could be used by others, and there are plans within WMO for establishing upper air stations on islands in order to improve the global network for the World Weather Watch. Some of these stations might be expanded into island observatories of the kind required. As a secondary task, the observatory could be used for other studies requiring continuous measurements, such as the monitoring of airborne pollutants and dust.

7. Geochemical Sections in the Ocean

An understanding of the factors which determine the distribution of pollutants in the ocean is closely connected with the understanding of the distribution of natural properties. The many techniques now available from geochemistry will assist in developing this understanding. A project for obtaining a densely sampled vertical section of geochemical tracers from north to south in the western sides of each major ocean basin (GEOSECS) has been proposed as part of the U.S. National Program for the International Decade of Ocean Exploration. These measurements will be of great importance in helping to understand the advection-diffusion field of the general circulation of the global ocean. This project, although large in concept, cannot complete the task of delineating many important features of the distribution of properties. Therefore we urge other countries, or groups of countries, to give serious consideration to mounting parallel and independent efforts: for example, meridional sections through eastern basins of oceans, or along parallels of latitude across ocean basins, or through certain adjoining seas of great interest such as the Philippine Sea, the Mediterranean Sea, etc. A related proposal for sediment study is to be found in the geological section. As a first step, a group of geochemists might meet to draw up a list of areas suitable for experiments and to carry out feasibility studies.

8. Pilot Studies in Velocity Spectra for IGOSS

Compared with our experience with the needs for station spacing in classical type serial observation surveys, our experience with the sampling needs for such modern oceanographic techniques as current measurement with moored current meters is still quite incomplete. Thus, when contemplating a program such as the Integrated Global Ocean Station System (IGOSS), it is desirable to have sample records of reasonable duration from typical measuring buoys and from several different geographical locations, in order to know whether sampling requirements are very uniform or very different from one part of the ocean to another. We need, therefore, to make some pilot measurements, and to determine such statistical representations as time spectra, particularly of velocity including the high frequency parts. We believe that some pilot experiments with buoys in different regions of the ocean are desirable, and recommend that efforts should be made to extend the period of measurement for at least a year. This project might be incorporated into the plans for the first phase of IGOSS and should be developed jointly by IOC and WMO.

9. Surface Current Measurement in the GARP

As part of the Global Atmospheric Research Program (GARP) a global drifting buoy experiment is being planned to extend over a period of about one year beginning in 1974 or 1975. In order to map continuously the transfer of momentum, heat and moisture from the oceans to the atmosphere during this period, it has been proposed that a fleet of about 700 free drifting floating platforms be distributed all over the oceans, particularly in the southern hemisphere, where there is little merchant shipping.

It is recommended that in addition to the measurement of surface sea temperature, air pressure, and air temperature (and possibly surface wind), simple current meters be installed beneath a portion of the surface buoys to permit a continuous monitoring of the motion of the buoy through the water. This, when combined with measurements of the changing position of the buoys, will permit a better knowledge of surface currents of the ocean and of momentum exchange between the sea and the atmosphere.

10. North Atlantic Ocean

Continuous plankton recorder studies in the North Atlantic from weather ships and merchant ships over a number of years have provided valuable information about the seasonal distribution of a number of species of zooplankton, including the eggs and larvae of commercial species of fish. These studies have also shown that large fluctuations occur in the abundance of different species. At the same time there have been marked fluctuations in the temperature and salinity of the surface layers that can be related, on the one hand, to the atmospheric circulation giving information about the behavior of such systems as extra-tropical cyclones and, on the other hand, to biological and fisheries events.

The recent development of sophisticated instrumentation, such as expendable bathythermographs and undulating oceanographic recorders, will allow these studies to be extended to the sub-surface layers and so provide synoptic, three-dimensional surveys of the temperature, salinity, primary production and zooplankton of the North Atlantic for use in fisheries research. This work hinges on the North Atlantic ocean weather stations and thus maintenance of this system is highly desirable from an oceanographic standpoint.

The project appears to be well under way in implementation and in further planning. Requirements are increased cooperation from weather ships in the North Atlantic and from certain merchant ships of the voluntary observing fleet.

11. Deep Water Masses

In recent years the part played in the formation of the deep waters of the North Atlantic by water from the Norwegian Sea overflowing the Greenland-Scotland Ridge has been recognized. Since this overflow takes place in relatively localized areas, it might be feasible to measure its rate over a long period of time. Suitable moorings and instrumentation can perhaps be most easily tested in the outflow from the Mediterranean which also provides an interesting example of such a phenomenon. It is proposed that the feasibility of measuring these inflows into the North Atlantic, which contribute to the main water masses found there below the North Atlantic Central Water, be examined with a view to starting such a study on an international basis during the expanded program.

Another important example of a deep water phenomenon occurs in or near the Weddell Sea where it appears that the greatest source of bottom water to the ocean circulation is to be found. Efforts to study the mechanism of formation of this water from surface ships are frustrated by the winter-time ice that covers the area. Recent efforts to monitor the formation of the water by leaving a few moored instruments under the ice during the winter have failed because of the unpredictability of the occurrence of ice during the summer when the instruments were to have been recovered. It is hoped that some nation will be able to make a suitable submarine available to its oceanographers for a period of several months, since we believe that the problem can only be solved by this means.

12. Estimated Magnitude of Projects

Although none of the proposals in this chapter have been elaborated in any detail, some rough estimates of the duration and ship requirements have been made as a first indication of the magnitudes of the programs envisaged. These estimates are summarized in the following table.

			Years	Ships	Research Ship-months per year
1.	Upper Ocean Data		20+	0	0
2.	North Pacific Ocean	a) general surface	20+	0	0
		b) gyre survey	20	8	48
		c) typhoon area	3+	3	9
3.	Coastal Upwelling	a) intense model area	3	1	12 *
		b) exploratory areas	?	?	?
4.	Arabian Sea		5	1-2	12-24
5.	South Atlantic		0.3	3	12
6.	Instrumented Islands	(each)	10+	1	12 *
7.	Geochemical Sections	(U.S. contribution)	2	1	9 *
		(other sections)	?	?	? *
8.	Pilot studies for IGOSS buoys	(each)	2+	1	2-3 *
9.	Surface Current Measurement in GARP		2	0	0
10.	North Atlantic Ocean		20+	8	0
11.	Deep Water Mass Formation	a) Mediterranean	4+	1	4 *
		b) Scotland-Greenland	4+	1	9 *
		c) Weddell	0.3	1 submarine	4

* heavy costs of special instrumentation are involved in addition to costs of research ship-time.

LIFE IN THE OCEAN

Introduction

The problems of biological production can be grouped into those of regional dimension and those of world dimension. Because most fish stocks live in relatively small areas, much of fisheries science has been conducted at a regional level. However, some problems concern systems which transcend natural regions; while some of these may be resolved by exploration, others are the less obvious problems of the science itself, and, by their nature, only slowly become identifiable.

Studies of marine production have as their object the increased use of the living resources of the sea. Since the second world war fishery production has nearly doubled in ten years and the present annual marine world catch is about 50 million tons, which represents approximately 15 percent of world animal protein consumption. It is possible that before the end of the century the annual world catch will be raised to 200-300 million tons. The large increase will come partly from better conservation of known stocks, partly from the further exploitation of areas of divergence, including upwelling areas, and partly from the discovery of other stocks in well known areas like the North Atlantic. Hitherto, fishery resources have come under exploitation from the explorations of fishermen. Many of the stocks which they have discovered are managed internationally. But a number of areas, particularly in tropical seas, remain unexploited and the value of their resources needs assessment. As fisheries develop, resources are sometimes exploited not as single stocks but more generally as meal or protein; thus ecosystems rather than single species must be studied. An understanding of ecosystem changes which will accompany increased exploitation is needed if the fishery is to be wisely managed.

The scientific problem is fourfold: firstly to discover productive areas and to complete an inventory of stocks in known areas. This leads to the second problem, the estimation of exploitable carnivores of less known areas by exploratory fishing. In the future fishermen may come to exploit all the carnivores and we shall need them to understand all the stocks and the relations between them. The third problem follows: that the ecosystems must be studied fully, with regard to various sizes of plants and of animals at each trophic level. In addition the production processes of each ecosystem must be determined in order to understand its functioning, as a basis for useful prediction and for man's deliberate manipulation to modify its structure for his own ends. Fourth: variations in concentration should be studied with reference to the environment, both physical and biological.

Rationale of the program

In his marine hunting, man is engaged in finding and exploiting patches of animals. Because primary production in the sea, effected by microscopic plants, is grazed by tiny animals, man is interested in catching only the primary and secondary carnivores, mainly the larger ones at that, and especially those which gather together at certain times in accessible places.

The world's fisheries have expanded by development of local fleets, and creation of long-range fleets, the latter relating to discovery of new areas far offshore and the former to intensive fishing of known areas. As a result of these technological developments, man catches a broader range of larger fish for freezing and can reduce more of the smaller ones to meal and oil, sauces and pastes, etc. Twenty years ago a few demersal stocks were fished to the limit of their production but as fisheries have expended in the last two decades, the exploitation of many more demersal and some pelagic stocks has been brought near that limit.

Techniques have been developed for assessment of stocks as single species or as groups of similar species, but intense fishing on a wider range of fish types in an area will make it important in the next decade or so to study more closely two hitherto neglected features of these systems, namely (a) the interactions between stocks, the relative abundances of which are determined by the stock and recruitment relations, (b) the dynamic relations between such stocks (as a single complex) and their food supplies. An understanding of these features will be essential for the management of new fisheries which may exploit in a particular area most of the species at one trophic level.

Although all marine life derives from the primary production in the photic layer, there are two great branches of the "food web": one of these leads from the phytoplankton to the zooplankton, and pelagic carnivores; the other leads from each of the links of this chain but mainly from the plankton, to detritus, the benthic detritus feeders including the crustaceans, and the demersal fishes. Although the last have been intensively studied in many regions, and by value are very important at present, even if not so great in quantity as pelagic fishes, the detritus-benthos-demersal system is far less well-known than the plankton-pelagic system. The reason for this is the technical difficulty of making quantitative investigations of benthos and its food.

In no case do we yet know the pathways and rate of flow of energy and organic matter, qualitatively or quantitatively, among all the major elements of an entire ecosystem. Such information is, however, needed for the rational management of future intensive fishing. Furthermore, extensive exploitation of tropical fisheries with their great species diversity, will necessitate broader measures of management than simple stock-by-stock regulations.

In view of the above we have concluded that the long-term and expanded program should in this field comprise a set of major projects designed:

i. to advance considerably our knowledge of global distribution and magnitude of primary production and herbivore production as a basis for area-to-area comparison, and as a first step in the prediction of production at other trophic levels;

ii. to fill in major gaps in our knowledge of the distribution and abundance of the primary and secondary carnivores, especially in parts of the tropics and southern hemisphere and on the continental slopes;

iii. to determine, in one or more selected zones of high productivity, the pathways of energy and material from the primary producers and herbivores to the demersal and pelagic carnivores as a basis for management of the resources, including measures to improve them;

iv. to determine the productivity characteristics of large concentrations of herbivores and small carnivores that might become exploitable.

Methodological studies will be associated with each of these projects. In particular there are certain problems which can only be resolved by more detailed research on the productive processes in the ecosystem. Further there is a need to standardize techniques.

In addition it is proposed that a wide range of expanded research programs should be directed and coordinated:

v. to improve utilization in and near coastal waters, especially through extension and scientific improvement of coastal aquaculture systems;

vi. to elucidate the relationship between parent stock and recruitment, especially in intensively fished stocks with a view to more reliable management of single or groups of stocks.

Project 1. Primary and Secondary Production Measurements

Carbon fixation measured by C^{14} techniques is now used as a convenient method of evaluating the productive capacity of the marine environment. Measurements should be taken on a global scale to give an idea of the order of magnitude of the total potential production capacity of the oceans and to permit regional and ecosystem comparisons.

Numerous measurements have been taken, some of them in time and space series; but data are scarce for most parts of the oceans and completely lacking for many other parts and seasons. However, the evidence is that most production takes place in areas of divergences and coastal upwelling and it is therefore proposed to concentrate studies in these areas.

Many of the projects proposed elsewhere in this report for physical observations could be used for radiocarbon measurements. Platforms and weather ships could be used to obtain measurements of variations in time. Observations should also be made along meridional sections of the three main oceans and it is desirable that primary productivity observations should be made wherever oceanographers work sections, especially in the central parts of the oceans. Laboratory facilities of bordering countries could contribute to this project.

Concurrently with carbon fixation measurements (and in the same areas) herbivore biomass should be measured by zooplankton sampling to determine herbivore production. These measurements should be accompanied by estimates of generation time such as can be obtained from laboratory experiments. The field samples should be measured for dry weight and carbon or caloric equivalents.

Zooplankton sampling of all the herbivores produced in the photic zone should be made, and account should be taken of the depth of the mixed layer and compensation depth.

Project 2. Exploratory Surveys

Although measurements of basic production are essential to long-term predictions of the productive capacity of ecosystems, the errors of estimation are still very large. There is no substitute for direct estimates of biomass, sizes and availability of exploitable animals, together with an indication of turnover rates derived from information about life history, growth and population structure. Exploratory surveys to obtain such information should play an important part in the expanded program.

Present fisheries are based largely on discoveries by fishermen exploring new areas with gears familiar to them. Even in intensively fished and well-known areas new fisheries have been developed as a result of introduction of new types of gear from other regions, sometimes guided in their search by acoustic methods. It is proposed that systematic exploratory surveys using a combination of acoustic survey methods with various fishing techniques should be undertaken in the expanded program.

It is not practicable to carry out exploratory fishing in all areas of potential interest. Several of these however, such as the principal upwelling areas and some of the continental slopes appear to be highly productive yet remain little known.

The following areas seem to be particularly worth explorating:

The Arabian Sea
The Caribbean and Gulf of Mexico
The Gulf of Alaska
The Indonesian and New Zealand Shelves
The Northwest African Shelf and the Gulf of Guinea
The Argentine and Chilean Shelves
The Antarctic Sea
The continental slopes down to 2,000 m.

The objective of exploration is to ascertain whether animals of fishable sizes are present and, if so, where and when they concentrate. While much of this information can be obtained by acoustic methods, identification of species, examination of sizes, composition and measurement of vulnerability require the evidence of exploratory fishing. In most cases acoustic detection can be recommended, even if only as a quick method of detecting the presence of organisms which might be suitable for exploitation. But calibrated acoustic techniques are also rapidly being developed as means of measuring abundance and degree of aggregation. It should be noted that aggregation, which is subject to seasonal and life-cycle variations, has an effect on catches as great as that of major abundance changes.

In searching the continental slopes for crustacean grounds, or the open ocean for concentrations of squids, acoustic techniques are of doubtful value at present. The expectation of finding these forms in high abundance and concentrations is great enough to justify the extra effort of exploratory fishing alone.

A powerful method for determining whether an area merits further explorations is fish egg and larva survey, using high-speed towed nets and plankton recorders. Such studies are of particular importance when associated with regional studies of primary and secondary production. The surveys can be carried out at sea by relatively unspecialized vessels, research vessels, or in the case of plankton recorders, commercial vessels. While these surveys merit expansion, there are major difficulties in identification of larval types, and in sorting routine samples and counting the organisms. The method is however, of such importance that it is recommended that shore laboratory sorting and identification facilities should be strengthened for the support of fish egg and larva surveys. The sorting facilities need not always be sited close to the survey areas.

There are extensive records available from geophysical surveys which are often of biological interest. For example, in the Arabian Sea, a notable series of echo records of fish was obtained on the precision depth recorder, and in the North Atlantic, studies for geophysical purposes have yielded records of the deep scattering layer across broad areas. Such records are valuable to biologists and should be made available for their use.

Project 3. Living Resources of the Antarctic Seas

The Antarctic Seas appear to contain living resources capable of supporting yields as great as or greater than present world fish production. Because of distance from markets and costs of logistic support only those of high unit value (mainly whales) have been harvested to date. Growing demands for high volume and low unit cost animal protein on a world wide basis indicate that demand for other large resources of the Antarctic Seas, and particularly krill, may be such as to make desirable the beginning of their harvest within a decade, especially if costs can be reduced. The U.S.S.R. has already begun exploratory work in this field; the U.S.A. and U.K. plan to initiate work; Japan and other countries have long harvesting experience in the region derived mainly from whaling.

Much basic research is needed on the distribution of the principal organisms, their life histories, their aggregation and migration characteristics, particularly as related to the environmental conditions. The task is formidable and exceeds the capability of any one nation within a reasonable time, although the combined meteorological, hydrographical and biological program being planned by U.S.S.R. will be a substantial step forward. The substantial buoy program proposed as one element of GARP might, toward the middle of the decade, also contribute substantially to this harvest objective.

Attention is called on the one hand to the very large benefits promised, in terms of living resource production, and on the other hand, to difficult economic and operational harvesting problems. Consideration should be given to the planning and initiation of a more broadly based international effort to resolve these problems in support of the initial efforts mentioned above so that these large resources of protein and edible oil can be made available to the world on economic terms as needed. A comprehensive study is required for this project.

Project 4. Detailed Ecosystem Studies

Fishing tends more and more to exploit the whole range of the larger animals in an ecosystem. Yet present knowledge of ecosystems is largely limited to a few single species, or at best to the average biomass at a number of food levels. Details of the feeding interactions are unknown for any major world ecosystem. To supply this information for at least two areas, one subject to minor exploitation and another subject to moderate to high rates of exploitation of at least some of the components, is a major objective of the scientific program.

Detailed knowledge of the production of plants and of animals at each food level, including the highest carnivores, will be needed in this study. Thus it is proposed to study major components of the diets of the animals and to examine size distributions of organisms and their foods at each level. At each level knowledge of the driving rates is needed, for example the reproduction rates of the algae,of the generation times of the herbivores and carnivores, and - for major consumers - of the kinds and rates of food intake and growth efficiencies. These are general problems which need to be resolved separately from field studies. The work on them should and could be carried out in shore laboratory bases before the ecosystem study is completed. A clear knowledge of the seasonal patterns of the environmental conditions under which energy exchanges take place and of the recruitment patterns of the various main carnivores should be established during the course of the study period.

The Arabian Sea is recommended as an appropriate low exploitation area in which part of this program could be carried out in much detail. Knowledge of this sea would be of benefit in any case since it seems likely to support a major world fishery. For purposes of comparison, it is further proposed that a similar study be undertaken in the Gulf of Guinea or the Peru Current, and in a heavily exploited area with considerable demersal as well as pelagic stocks such as the South China Sea and Gulf of Thailand.

Successful conduct of such a program would require the services, almost continuously, of an appropriate fishery research vessel in each region. These vessels would need to be stern trawlers of moderate size with laboratory and modern hydrographic facilities, including *in situ* temperature and salinity instruments. It should be equipped for acoustic fish surveys and plankton sampling. While much of the work on primary production and preliminary processing of the samples of plankton and fish samples would be carried out on board ship, modest support laboratory facilities on shore would be required.

In this program the pathways of energy in the pelagic phases of the ecosystem could be traced and, with appropriate laboratory support, the values of the principal parameters and efficiencies of energy transfer could be determined. This is, however, a difficult undertaking, and in the eventuality that a pollutant or "natural tag" should appear in a study area, it should be studied as an adjunct to the laboratory methods (see the marine pollution chapter).

Tracing energy pathways through the benthic-detritus system to the demersal populations is extremely difficult and presents many methodological problems. There is no information on the input rates of utilizable organic material to the sea-bed, although this must be the driving parameter of this system. However, measures can be made of standing crop and possibly of the production of many of the commonest benthic and epibenthic animals. Estimates of the transfer of food in the principal demersal carnivores can also be made, and hence limited estimation of benthic production is possible.

The early critical life history stages of many benthic carnivores are pelagic and their places in the pelagic energy cycles should be determined. A study period of ten years is likely to offer important information on the survival of such larvae and its relation to variations in abundance of adults. Equally importantly, the study should yield information on the division of energy for production between reproduction and growth among various carnivores. Such information is vital in appreciating differences in response of the component species to exploitation. In making available such data, the study will contribute to the general study of the problem of recruitment and stock size which is being pursued in many areas through the world. It will also permit application of new insights to fishery development in the study area. As with some other projects, this should also provide information of value for the development of aquaculture.

Project 5. Development of Coastal Aquaculture and Improvement of its Scientific Base

This term is used here to mean the variety of activities by which man has sought to utilize, in a form useful to him, more of the organic material found in abundance in many inshore areas, estuaries, saline and brackish lagoons and mangrove swamps throughout the world. Such areas may be rich in plankton and detritus either because they have a high productivity or because water movements - tidal, currents, flushing - are ensuring a more or less regular flow of such materials into them from the open sea or down rivers. Such areas of limited extent usually have relatively high natural production. The characteristics of the animals, whose yield man has sought to improve, are: (a) that most of them are herbivores or detritus feeders, and (b) they are either attached (bivalves) or have a reproduction - feeding migration pattern such that they will congregate and hence can be easily harvested in the inshore or brackish areas(grey mullets, milkfish, shrimps). Many of the latter type depend for their success on influx of recruits from offshore nurseries. Such animals typically have relatively high market values, and there is a considerable potential for the expansion of economic production. In many cases this may require only the application or adaptation of existing techniques. Scientific research and advice could however, hasten such expansion as well as give a necessary basis for further evolution of the techniques themselves; accordingly a wide range of research projects might be developed within the expanded program. Although not all such projects would require international cooperation on a large scale as is envisaged, for example in cooperative programs in the open sea, a very high degree of communication and information exchange as well as joint planning and training would be essential in each subject area; a small beginning in such cooperation is being made in, for example, the IBP Grey Mullet Project.

The kinds of activities envisaged might include:

(a) World-wide survey for potential culture areas with reference to: topography, bottom sediments, small-scale oceanographic features including temperature and salinity distributions, tides and currents; local sustained high productivity or concentration of organic materials; determination of culture techniques and selection of species for each suitable area and estimation of the potential yield from each.

(b) Comprehensive studies (with experiments) of the ecology of cultured organisms and of their environments in selected areas, to give basic information for:

i) ensuring continued natural recruitment (including that from outside of the study area) and improving it; developing and maintaining artificial recruitment; breeding better strains; combatting diseases;

ii) improving the environment by enrichment, creating suitable habitat (including the use of artificial structures), control of predators;

iii) more efficient use of food supply by manipulating species composition, removing competitors, introducing new species.

(c) Studies of "water quality" requirements of cultured organisms - particularly important in connection with the sensitivity and vulnerability of such systems to pollution, because culture on coasts and near to human settlement is close to major pollutant sources, and because filter feeders appear particularly to accumulate certain pollutants.

(d) Extensive use of underwater observation facilities for detailed behavior studies as well as ecological survey.

Such a pattern of activities would not only have a direct bearing on economic production and hence be of special interest to developing countries where coastal aquaculture has a high potential, but would also contribute substantially to our knowledge of biological production processes in the open sea and hence to solution of the problems of management, and eventually to more extensive development of mariculture.

Project 6. The Stock and Recruitment Problem

Fishermen have always believed that fishing affected the breeding of fish. In the early stages of research, biologists believed that, within the range of stock variations studied, the recruiting year clases were largely independent of the size of the parent stock and hence were not much affected by fishing. It is now clear that fishing at levels of intensity now being reached can affect the reproduction of fish. Indeed the major problem facing fisheries scientists at the present time is that of the variation of recruitment at different levels of fishing. The problem becomes particularly important when stocks are very intensively fished. It is thus of immediate priority in relation to some fisheries but the spread of fishing is now such that in the next decade it is likely to be of much more general concern.

The variability of year classes is determined in at least three ways, firstly,by the success of matching the timing of spawning to the cycle of production in the sea; secondly, in the modification of this process by long-term changes in the physical environment, and thirdly, by the variations in the density of the stock itself. These three effects raise several scientific problems. That concerning the success of matching the reproduction of fishes to the production cycle is essentially a matter of estimating changes in timing and amplitude of the cycle as a function of the ratio of compensation depth to depth of mixing. Long-term climatic changes which constitute the second problem may sometime owe their dramatic effects on the fisheries to trends in time of these same processes, i.e. the progressive increase or decline in the success of matching spawning to production. The third problem, variations in the stock itself, calls for studies of density dependent mortality, by simulation at sea and experimentally.

One facet of the stock and recruitment problem, the long-term changes in the physical environment, is discussed in another section. The other two facets do not need to be studied on a world scale although solutions may emerge from the combined results of several groups of biologists each investigating this problem in relation to a particular intensively fished stock or stocks. However, it is likely that some of the studies proposed, for example, of ecosystems and in upwelling areas, will bear on the detailed work needed for the solution of the stock and recruitment problems. In particular three lines of work are needed. The first is the construction of models of the processes which might determine density dependence and also of those processes which help determine year class strength independently of density. The second is the execution of laboratory experiments needed as the models are tried out, for example, on growth, behavior, food capture and escape speeds of fish larvae. The third is the estimation of density-dependent mortality at sea. It is obvious that the three lines of work interact considerably and that they should not be pursued independently of each other.

The Requirement for Environmental Information

It is general experience that highest biological activity in the sea occurs in frontal or transition zones such as areas of upwelling, divergence or convergence. Bottom type is of importance to some demersal species, and may even be to some pelagic species, and is of particular importance in determining the distribution of crustaceans and fish on the continental slopes. In selecting areas where studies of primary and secondary production or exploratory fishing should be concentrated, information on these major active areas of the world oceans is needed.

It is commonly accepted that an understanding of environmental characteristics is required for understanding and prediction of events related to fisheries production. However, the interactions take place over a wide range of frequencies of time and space scales of both organisms and environmental characters and inquiries about these relationships must focus on the appropriate part of the spectrum.

It should also be noted that the presence of organisms may also produce significant effects on the environment. No suitable broad theory exists for the interaction between organisms and their environment to guide the biologist in specifying the environmental information he requires. Progress will be made in solving this problem through jointly planned programs of observation and analysis.

In the biological production programs outlined above, the needs for detailed information on environmental parameters and dynamics vary according to the objectives of the program and the phenomena studied. For example, since photosynthesis is sensitive to the amount of light, calculation of primary production in a water column depends on knowledge of amount of light at various production sites and of vertical turbulence. Metabolism and activity of zooplankton are sensitive to temperature and in their behavior zooplankton respond to light and food abundance changes which therefore influence their production. Differences in reproduction rates, buoyancy or swimming ability may give rise to differential distribution related to temperature and small scale turbulence. Since the organisms are relatively short lived, with rapid response times, measures of local environment conditions over short time periods are relevant to the study of primary and secondary production and techniques for making them are established parts of the biologist's observation routines. Such data are probably sufficient for interpretation on the broad scale of the primary and secondary production studies outlined. Additional information on seasonal environmental patterns may frequently be useful in weighing results of surveys to provide annual averages.

Exploratory surveys for concentrations of animals, outlined as the second biological study, require environmental information of a different type and scale. Most of the organisms at which the studies are aimed show diurnal and seasonal migratory behavior. Since most are relatively long-lived, interaction of this behavior with currents, local turbulence or type of bottom will have an important influence on regions of occurrence and degrees of dispersion within regions.

One cannot generalize about the specific kinds of environmental information which would assist in limiting the search to local areas of most probable abundance. However, general physical information on frontal or transition zones, such as major oceanographic convergences or divergences, thermoclines or local areas of stability within otherwise active areas will be useful, since these regions are likely to have high biological productivity. More detailed data on water mass patterns and distributions in relation to areas and seasons of abundance and concentrations will be needed to support fishing operations. In connection with exploratory work in areas of both high and low abundance hydrographic information should be collected to permit the study of possible relations of aggregations to physical features. In the case of demersal organisms such as shrimps and flatfish, information on bathymetry and sediment types is useful. There will therefore be a need for new charts of bathymetry and of sea-bed type.

Understanding the trophic structure of a major ecosystem requires detailed environmental information of many kinds on a variety of scales. For example, it is well known that the feeding success of a predator depends as much on local distribution, hence availability, of its prey as on the average density of that prey in the predator's area of search. Relative distributions of predator and prey will almost certainly depend on the distribution and dynamics of water properties on scales which will depend on the size and mobility of the organism. The abundance of animals in a region often depends on their circuits of migration. In order to remain in that region they exploit currents in subtle ways. For example, a current may be used on a feeding migration and a counter-current on a spawning migration; animals must leave or join the currents at particular places because spawning and feeding grounds are found in the same place year after year. The requirements for knowledge of such phenomena, in addition to information on temperature and light are varied and complex. In most situations these factors are so little known that their nature and the dependence of biological events on them should be the subject of joint investigation.

The foregoing implies that problems of aggregation in animals and of their dependence on physical processes are increasingly recognized as important matters for oceanographic research, particularly in fisheries. Forecasting the area of occurrence of migrating fish and measuring (for management purposes) their abundance when they are highly concentrated in local areas for varying periods (possibly related to the strength and persistence of oceanographic features) are important aspects of this problem. The study of inshore regions is another special example of the need for this information. The high biological production of embayments, estuaries and shore zones seems to be a result of a possibly sensitive balance of biological dynamics with rates of exchange, diffusion and flushing processes in the water, the general pattern of which responds to meteorological conditions. Special efforts should be made to understand these important systems.

Finally, it should be noted that in marine ecological studies, a subject of special difficulty is the benthic production process. The two principal areas of difficulty are the estimation of the input energy in the rain of detritus or benthic photosynthesis, and the influence of the nature of the sediments and their dynamics on the occurrence and survival of the organisms. Progress in this important scientific field may require the cooperation of sedimentologists and biologists in development of appropriate methodology and instrumentation.

Instrumentation

There are general needs in instrumentation for biological use, which fall into three groups: (a) detection of fish under certain special circumstances, (b) measurement of the input of organic material to the sea-bed, and (c) observation of details of the behavior of fish individually and collectively to establish the nature of certain mechanisms (including the reactions of the fish to fishing gears). It is unlikely that a single instrument will suffice in any category and a disparate array of instruments might be needed.

At the present time acoustic instruments cannot be used for positive detection of shrimps or flatfish, because the shrimps and many flatfish live on the bottom. Detection of such animals in shallow water might be achieved by high frequency equipment towed rather close to the bottom. A more severe need is of equipment for detection of fish and squid, perhaps including shrimps, on the continental slopes down to 1,500 m; it is possible that very high powered equipment with very narrow beams might be used for this purpose.

The fall of organic material to the sea-bed has seldom been measured. It has been suggested that sticky collectors might be placed on the sea bed to catch the rain of organic detritus. In very shallow water, organic material is generated by algae living in and on the bottom. Methods are needed for estimating both the descent of organic material and its generation by algae *in situ*.

Crucial details of fish behavior remain unknown. For example, the mechanisms of predation cannot be fully elucidated until the attack ranges of predators and the escape speeds of prey can be measured in the natural habitats. Divers are limited by depth, however, and cameras by their lights and lack of attention to the relevant detail, while acoustic equipment can only resolve rather coarse details; some of these limitations, of course, apply also to submersibles. A combination of methods, or an improvement or adaptation of techniques (such as in holography, or by the use of large observation tanks) might lead to the solution of this problem.

MARINE POLLUTION

Introduction

Nature of the problem: The marine environment is receiving, in increasing amounts and in increasing variety, waste substances from our civilization. The world ocean does not have an unlimited capacity to absorb such materials. Already unsatisfactory, high levels of some pollutants exist in some parts of the ocean and may be imminent for others. Since the ocean is a resource for food, including the practice of aquaculture, transportation, amenities and raw materials, and relates to the general health of man, any losses of area or restriction of uses through contamination by man may only be prevented by rational policies based upon effective research and monitoring. A substantial monitoring program might also act as deterrent against the pollution of one oceanic area by activities in another part of the world. (The term "marine pollution" is used as defined by a SCOR/ACMRR Working Group and accepted by the IOC Working Group on Marine Pollution: "Introduction by man of substances into the marine environment resulting in such deleterious effects as harm to living resources, hazards to human health, hinderance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities".)

Materials can be transported over vast distances in the atmosphere and the ocean from the site of continental injection. The pesticides applied on the African continent have been detected entering the Bay of Bengal and the Caribbean Sea following transport in the summer monsoon and northeast trade winds respectively.

Further, some pollutants may spend considerable times in the sea water and in the marine biosphere before accumulating in the sediments or before decomposition. The additional lead entering the oceans today over that from natural processes, as a result of the utilization of lead tetraethyl as an anti-knock agent in internal combustion engines, will in principle be measurable for the next thousand years or so.

Finally some materials, instead of being dispersed throughout the ocean after introduction, accumulate in one or more parts of the marine environment and biota. The halogenated hydrocarbon pesticides are concentrated in the lipid phases of the biosphere. Hence such organisms as fish, birds and copepods, which contain high amounts of body fats, are likely oceanic reservoirs for such materials.

Although today we can define only a few hazards resulting from the controlled, accidental or indiscriminate release of industrial and domestic materials to the sea, the problems will grow with increasing human populations and with increasing industrial activities unless anti-pollution measures are taken. We must examine each pollutant to ascertain (1) if deleterious effects are possible, (2) if monitoring is necessary and possible, and (3) what actions should be taken during the expanded long-term program.

Types of pollutants: Nearly all of the materials used in the world economy become or are converted to wastes. To obtain some appreciation of the quantities we will be dealing with, some recent statistics of U.S. consumption can be cited. About 1.5 thousand million tons of fossil fuels are burned annually, yielding to the atmosphere water, hydrocarbons, oxides of carbon, nitrogen and sulphur, as well as particles of ash. The bulk of such combustion products will eventually end up in the oceans. One can compare this amount with the estimate of 10 thousand million tons of carbon fixed by photosynthesis annually in the photic zone of the world ocean.

Up to one thousand million tons of minerals, food, and forest products are used by U.S. society annually. Upon degradation, much of this passes to the air as carbon dioxide and water. However, two heavy metals, lead and mercury, enter the marine environment, following world usage in amounts equal to those of the natural discharge of rivers. Other metals such as arsenic, selenium, iron, copper and zinc are also being discharged and are building up in the oceans, although not as yet perceptably. Their known toxicities to organisms make such inputs of profound concern.

The waste products of industry, agricultural and other medicants, industrial solvents and reagents, radioactive nuclides from nuclear devices and nuclear reactors, and domestic wastes are examples of modern civilization's metabolic waste products that have been measured in sea waters. In some cases tragic events have preceded detection of the pollutants.

Adverse effects of marine pollution: The wastes and poisons already released to the marine environment have resulted in a host of well-documented adverse effects. The following listing illustrates the variety of impacts upon our marine surroundings, our plant and animal communities and ourselves.

1. Contamination of beaches with discharges of inadequately treated sewage has led to bacterial and virus infections, as well as reducing the amenities on which the tourist industries in certain areas are based. Infections can arise by eating raw shellfish harvested in areas subject to such discharges and the industries involved are adversely affected.

2. Oils spills have contaminated beaches, killed sea birds and spoilt the flavors of fish and shellfish. The methods of dealing with such spills have introduced additional pollutants to the environment, such as surface active agents and their solvents, which themselves were toxic to marine life.

3. The accumulation of the insecticide residues and insecticides, such as the halogenated hydrocarbons in the fish, birds and seals of the marine environment, provide health hazards to such predators as man and birds. Further the reproductive successes of some predatory birds have been reduced, alledgedly due to their high pesticide residue contents.

4. Filter feeding invertebrates are sensitive to changes in the quantities of dissolved copper, zinc and mercury, which are rare in sea water but often common in industrial wastes. Distortion of the flavor and the death of the shellfish can result, and poisoning of consumers can occur, sometimes with fatal consequences.

Previous monitoring systems: The steps taken to deal with radioactive pollution of the sea following the development of nuclear energy provide a useful guide for the consideration of monitoring pollution from other sources. For example, the United Kingdom, which has a highly developed nuclear power station system, has established a program whereby each source of radioactive pollution in the marine environment around the British Isles is monitored regularly at frequent intervals. Further, the pathways whereby radioactivity might reach the public are similarly monitored. The results of these surveys are published annually so that the world at large is informed of the situation to date. More extensive literature on the international aspects of monitoring the marine environment for radioactive pollution can be obtained from the International Atomic Energy Agency. Such procedures have much to recommend them and clearly suggest that monitoring programs for other pollutants on an international scale might be possible.

THE MONITORING PROGRAM

We therefore propose that a world-wide system of pollution monitoring should form part of the long-term program. This system should deal only with pollutants that are now, or might become, of major concern, and monitoring would take place at vital points in the air, sea and rivers and the marine biota. To bring the system into being, techniques for measuring various pollutants will have to be developed and, if possible, standardized, and marine test animals will also have to be developed. Certain laboratories will have to be selected to carry out the required measurements on behalf of all nations and special studies may have to be carried out in selected areas subject to heavy pollution of particular kinds in order to test the adequacy of the monitoring scheme. Arrangements for the exchange, interpretation and publication of data will have to be made.

We envisage that the overall monitoring program might take the following form, parts of which are elaborated upon in subsequent paragraphs.

.....the collection of samples from the various environments and biota for submission to analytical centers.

.....analyses to be carried out at these centers.

.....reduction of results and submission to the oceanographic data centers.

.....evaluation, interpretation and proposals of action by a central body.

.....yearly publication of results of the monitoring program.

Atmospheric injections: Fall-out of pollutants from the atmosphere is an important factor contributing to pollution of the sea. Many of these impurities, e.g. smoke, sulphur gases, gasoline vapors, radioactive nuclides, etc. are introduced into the atmosphere as a consequence of industrial, agricultural and social activities. Other impurities, e.g. continental dust which may itself be contaminated, may be raised into the air by winds or by convection processes.

A proportion of the foreign matter entering the atmosphere in the ways described will return reasonably quickly to the earth's surface as a result of gravitational settling. However, the majority of the contaminants will be too light for gravity to be effective. As a result of vertical motion they may be dispersed throughout the troposphere, and some may even enter the stratosphere. During their history in the atmosphere they will also be transported by the horizontal wind systems of large or small scale which are considerably stronger than the vertical currents.

Apart from any effects of chemical degradation, these very light contaminants are eventually removed from the atmosphere by fallout in rain or by dry deposition due to the slow process of vertical diffusion. Fall-out in rain is by far the more effective process, and rain falling on the oceans will therefore account for a high proportion of the marine pollution which is attributed to the atmosphere.

The major sources of industrial or other man made pollutants are well known and, with the aid of surface and upper air weather charts, reasonable estimates can be made of the life history of impurities released from these sources. Such quantitative advice would not, however, be a substitute for sampling and measuring over an adequate network of points the amount of pollution entering the sea from the atmosphere. Plans should be drawn up for direct air sampling of impurities and for the collection of rainwater samples for subsequent analysis at selected laboratories.

Coastal injection: rivers and outfalls, both domestic and industrial: Rivers and outfalls are the main carriers of domestic wastes, as well as products resulting from agricultural and industrial operations. In addition, radioactive medicinals, used in hospitals, have been detected in sewer outfalls.

The potential hazards will vary quite widely from area to area and perhaps the monitoring programs will often have to be designed to assay the singular inputs of the system in question.

Ships discharge and offshore drilling and mining: The input of petroleum products to the world oceans may already be having ominous consequences. The chronic problem involves the transport of one thousand million tons of petroleum across the world ocean annually, with a yearly increase of 4 percent. It has been suggested that more than 100,000 tons enters the ocean through accidental or intentional discharge or leakages, an amount about equal to the production of hydrocarbons by the marine biomass. Two accidental releases, from the Torrey Canyon and the Santa Barbara offshore drilling incidents, each appear to have introduced about 100,000 tons to more localized areas with more visible consequences in the loss of birds and beaches. Since such petroleum products as the hydrocarbons would be expected to end up in the lipid containing materials of the sea, it is not too surprising to hear of reports of fish tasting of petroleum.

Several cases are on record of mining wastes, like nickel and iron residues, disturbing the marine environment and its resources. Cargoes hazardous to marine life such as pesticides and various other noxious chemicals are carried on a very large scale by merchant ships. Accidents to such ships could release huge quantities of toxic wastes into the sea, and nuclear power plants used for propelling marine vessels could conceivably contaminate large areas. Industrial, domestic and radioactive wastes are dumped at sea with consequences which need studying.

Transport within the marine environment and ecosystems: Since most pollutants enter the marine environment through surface waters, our dominant concern will be with downward and lateral transports in preparing models of dispersion. Such models are of importance in the initial design of monitoring systems. Rapid removal of pollutants from the mixed to the deep layers of the ocean, either by biological or physical processes, may eliminate a need for monitoring in an extensive way. To gain an entry to the general problem we may divide the pollutants into two classes: the dissolved substances and the particulates, both solid and liquid. The latter group will be subject to gravitational transfer to deeper zones and to uptake by filter feeding organisms, or to dispersal about the surface, if retained there by one phenomenon or another. The dissolved phases can be subject to movement with the water mass, to uptake and concentration by the biosphere, or to adsorption by the sedimentary particles.

Other pollutants may enter the bottom waters of the ocean from mining and dumping activities. The necessary information on the deep oceanic circulation needed to forecast their dispersion is considered in the section on ocean circulation.

Particulates, such as oil films, are transported under the combined influence of winds and current systems. Some information on such movements is available from the Santa Barbara discharge and from the Torrey Canyon incident; such data may be useful for prediction in other areas.

The biological transport is not as yet very useful for prediction of the dispersal of pollutants. Studies on the fates of pollutants entering the ocean from the atmosphere might be made with profit utilizing the community which lives at the air-sea interface. Such organisms might be especially diagnostic in recording levels of input, if one of their members is able to accumulate the pollutant.

The length of time a given pollutant spends in surface waters varies with its involvement in biological processes. Such elements as silicon and lead, which are highly concentrated by the low trophic levels, spend only a few years in the mixed layer, while other substances, not so involved, may spend much longer time periods.

Substances to be monitored: Some *a priori* criteria to determine whether or not to monitor a man-made product in the marine environment may be made:

1) The production and release to the environment amounts to a significant fraction of the amount introduced by natural processes.

2) The materials have been detected in marine organisms at levels known to cause biological disturbances.

3) The materials are being injected in the marine environment in large amounts and cause, or may cause, losses of products of commerce.

4) Potential dangers could result from high inputs of a substance alien to the marine environment.

5) The materials contain substantial amounts of toxic organisms and substances.

6) Release is possible from nuclear reactors and devices with regard to the long-lived, high energy particle emitters.

Environments to be monitored: Once the substances that may be toxic or deleterious have been identified, and the feasibilities of monitoring them confirmed, then the following factors might be monitored:

1) The atmospheric fallout at land and ocean stations, including island stations in the vicinity of (a) all primary wind systems like the year-round jets and trades in both hemispheres; (b) secondary wind systems such as the monsoons in the Indian Ocean area or regional winds like the winter Harmattans.

2) Waters and suspended loads of selected river systems draining industrial and agricultural areas, coastal lagoons and mangrove systems.

3) Waters and suspended loads of selected outfalls entering the oceans from high population or industrialized zones.

4) Waters of the oceans with emphasis on the mixed layer and dumping and mining sites.

Organisms to be monitored: The members of the biosphere, on the bases of quite different body compositions and activities in the ecosystems, may provide the most useful indicators of the levels of pollution in a given area. In some cases they may act as integrators through uptake of a substance over wide areas, for example, the tuna or birds in assimilating radioactive species; in others, they may quite specifically monitor a given domain, for example, the surface diatoms, dinoflagellates, or bacteria. The following criteria might be used:

1) For particulate pollutants, organisms effective in concentrating particulate phases above a given size, such as the filter feeding bivalves.

2) Organisms known to monitor a given area, such as attached algae.

3) For dissolved substances, organisms known to concentrate them, such as fish for zinc and cadium or the tunicates for vanadium.

4) Wide-ranging organisms such as the tuna.

It should be noted that several of the criteria may be satisfied by a single species.

Development and standardization of techniques: Many of the substances marked for monitoring will be in extremely small quantities in environmental samples, will need extensive concentration procedures prior to analyses, and perhaps will require rather sophisticated instrumentation. To alleviate such difficulties, the establishment of analytical centers to which samples are sent appears especially desirable. Further, such centers will provide economies and decrease the requirement for inter-laboratory comparisons.

The development and standardization of analytical procedures is a prerequisite to a rational monitoring program. Oftimes high precision must be traded off against economies of time or personnel, and the nature of the monitoring program for a given substance will dictate the circumstances under which it is treated. Even somewhat imprecise values have proven somewhat useful in the past. For example, the concentrations of halogenated pesticides determined in fish are subject to uncertainties in adequate sampling in time and space, as well as in the lack of interlaboratory comparisons. Nevertheless, the order-of-magnitude levels, ascertained in many laboratories, have clearly established that a real pollution problem exists.

An extensive effort should be made in all programs from the beginning to ensure that maximum information is obtained from a minimum number of analyses. There should be sufficient flexibility so that techniques can be changed, altered or discarded with ease.

Development of marine test animals: The selection of representative test species is an important method in freshwater pollution studies, as well as medical and pharmacological investigations. While results of tests on these species cannot be directly applied to other species, or cannot alone permit prediction of more complex effects of chemicals passing through the food web, they can be compared among themselves, can provide a reference base for the ecological studies, and, if carefully selected, can give first approximation to the likely responses of other similar organisms. However, apart from radioactivity studies, and some recent tests of detergents used to disperse spilt oil, few marine organisms have been used for testing of toxicity of pollutants and of biological and sub-lethal effects.

The characteristics of a set of suitable test organisms might be that:

1) Each species is widely available and can be kept fairly easily in the laboratories.

2) A range of feeding types is included.

3) Their general biology is rather well known.

4) They have closely related species distributed globally which have similar behavioral and ecological tolerances and needs.

It is suggested that the long-range program should include: (a) the selection of a number of such species; (b) the determination for each species of maintenance techniques, metabolic characteristics and other relevant biological properties; (c) the conduct of tests on a number of the critical pollutants.

Special investigations: Our present knowledge about the impact of a single substance upon the marine environment is quite sketchy and corrollary investigations to the main monitoring program seem especially desirable. In a given region the effects of a single pollutant should be monitored and the effect on the environment studied.

Perhaps the study of a region subject to high oil pollution, such as the Persian Gulf or the Maracaibo regions, would provide a scale model for the world ocean problem. The inadequacies and weaknesses of a monitoring program might be subject to examination in detail by appropriately designed experiments in such an area.

The use of satellites for monitoring should receive attention. With such devices, it may be possible to monitor large areas continuously and at reasonable costs. The technology may exist soon to assay thermal and petroleum pollutions on the surface of the oceans. Inaccessible areas of the oceans may be monitored on special occasions by oceanographic vessels.

At the same time it is essential to study the acute and sub-lethal effects of pollutants on the biology and life cycles of marine organisms (e.g., changes in behavior, in hormone and enzyme function, modifications in fertility, etc.) as well as the composition and dynamics of marine communities. The work begun under IBP in establishing ecological base lines against which could be measured changes in the marine environments, should be pursued. Information of this nature is in some cases essential as background for the establishment of legislative control over marine pollution.

The material budget: Material balance formulations are often as desirable for predicting future events as they are generally unavailable. Still it appears a worthwhile exercise to begin any monitoring program with a model and appropriate assumptions which lead to mass balance calculations.

Recently several models of mass balance have been presented and may have broader applications. On the assumption of the removal of lead tetraethyl and its degradation products from the atmosphere to land and sea in proportion to their relative areas, coupled to the known production of this parent substance with time, a non-steady state model for lead concentrations in the ocean has been developed. Workers in radioactive fallout, on the bases of the distribution of substances between various environments and transfer mechanisms, have been able to formulate a mass balance for strontium-90 which agrees markedly well with observations.

Input to basic marine science: The study of marine pollution can be useful to various branches of marine science. Radioactive pollutants are most effective tracers of water mass movements and of mixing processes, as well as providing time clocks in the marine environment. Further developments on the use of other pollutants as tracers for oceanic circulation are considered in the section on ocean circulation. Some contaminants, in principle, can be used to indicate routes whereby energy and materials flow through the ecosystem, and the rates of which energy and material are transferred from one trophic level to another. This subject is also discussed in the section on life in the ocean.

The report on the health of the ocean: With the present speed of industrialization in various parts of the world and the change in human communities and ways of life, it is necessary to have a detailed and quantitative picture of the source, distribution and movement of the main pollutants in the marine environment and organisms as a basis for action. Such an overall picture can only be obtained if a world monitoring system is put into effect and if all the data collected as part of national or international programs are made available to the world community to facilitate their analysis and interpretation. This can be achieved if all data are submitted to World Oceanographic Data Centers and the FAO Fisheries Data Center. It should be the duty of a central service to produce on a world basis an annual review of the state of the ocean and marine resources, from the point of view of marine pollution, and to forecast long-term trends so that governments can take in advance the steps required to counteract its effects.

DYNAMICS OF THE OCEAN FLOOR

A. PRINCIPAL SCIENTIFIC PROBLEMS

Before discussing the scientific paths that may lead to the use of the mineral and fuel resources of the ocean floor, we have to point out that our ideas about non-living resources, unlike those concerning some of the living resources which have been exploited for millenia, are based on very few facts and much speculation. We have a fair amount of information on the resources of the continental shelf, in part because its geological features are comparable with those of the nearby continents. Doubtless the shelf will be one of the critical areas of underwater exploitation, but its area is only about 10 percent of the area of the ocean. Our knowledge about the continental slope is much less that that about the shelf. Only its similarity in structure makes us believe that it may be as rich in resources as the shelf. In the deep sea, our knowledge is only sporadic and accidental. Discoveries such as of the oil traces on a salt dome in the deepest part of the Gulf of Mexico and the hot brines of the Red Sea have been limited to marginal seas. The open ocean, which covers more than half the globe, has offered up till now only manganese nodules, and some chromites in the rift zone. But the structure and material of some deep basins and of the ocean ridges suggest the possibility that there may be much richer resources. To determine if these resources exist, we need to study in detail the processes of formation of the ocean basins and ridges. Thus many of the following proposals are not concerned directly with a search for resources, but with the ocean floor dynamics that may lead to their discovery.

An important practical result of geophysical and geological studies of the ocean will be the help they can give in explaining the origin and formation of continents, not only because the latter contain large amounts of marine sediments which form reservoirs for oil and gas, but because the deeper rocks of the crust and mantle are often more easily accessible under the ocean. In many respects the oceans are the key to the continents.

Principal scientific problems to be solved in the future will be:

1. Dynamics of the crust and mantle in the principal tectonic systems in the oceans, including mid-oceanic ridge-rift systems, trench areas and marginal seas, mediterranean seas and continental margins, and the deep sources of material and energy for tectonic processes.

2. Sources of sediment material, and energy of sedimentation processes.

In addition, the economic consequences from these processes must be carefully examined.

Dynamics of the Ocean Crust and Mantle

Among the major scientific events of the last two decades are the presentation of new ideas about the origin and history of the ocean basins, based on geophysical and geological marine investigations using recently developed instruments and methods. Further development and use of these scientific tools offer great promise for making critical observations which will help to prove and refine or disprove these ideas. At present, it seems possible that large areas of the sea floor have been formed during the last epochs of geological time by intrusions along the great mid-ocean ridges and subsequent lateral movement away from the ridges, while other areas may have been formed by subsidence of continental blocks; still others could be remnants of a much older sea floor.

Advances in understanding of the physico-chemical mechanisms of ascent through rift zones and descent through trench-arc zones of materials and energy from the earth's interior require theoretical and often speculative considerations about energy sources and physical properties deep within the earth. The initial chemical composition and physical state of the earth and its evolution over several billion years; the heat energy by radioactive decay, the release of gravitational energy and the heat produced by phase changes; gravitational differentiation and zone melting; energy transfer by thermal convection, conduction and radiation, all must be taken into account. Marine observations in turn present boundary conditions for evaluating basic ideas and hypotheses about the earth.

(a) Mid-oceanic ridge-rift systems

It has been demonstrated in recent studies that new materials are supplied to the surface from the upper mantle through the great mid-ocean ridge-rift systems. But to understand the actual processes of formation of new crust it is necessary to obtain greater knowledge of:

1) The fine structures of the crust and upper mantle near the ridge crests, especially the possible mosaic structures of the crest zone, the distributions of basaltic, ultrabasic and metamorphic rocks, their correlation with the linear magnetic anomalies and their radiometric ages, the origin of lenses of low seismic velocity (7.0 - 7.5 km/sec) under the roots of the rift zone and the causes of their seismic anisotropy and of the seismicity of the ridge-rift system. The stress patterns associated with the seismicity of both the ridge crest and the transform faults across the ridge would be particularly informative.

The possible branches of the rift systems, such as Cocos Ridge, Carnegie Rise, Chile Rise and Labrador Rift are also of great interest.

2) To determine the extent or limit of the present system of spreading in both space and time, the outer boundary, if existent, of the crust formed by the present ridge-rift system must be delineated through extensive magnetic, seismic (both refraction and reflection) and petrologic surveys.

The possibility of the existence of ancient ridge-rift systems in presently stable areas must also be examined in connection with the origin of the part of the ocean which may be outside the present spreading system, "Darwin Rise" being an example.

Investigation of these questions will require precise mapping and cross-correlation of data on topography, magnetic field, gravity field, heat flow, petrology and mineralogy of solid rocks and sediments, seismic and magneto-telluric measurements and seismicity.

(b) Trench-arc and marginal sea systems

These systems are also tectonically highly active but in other respects they are in marked contrast to the mid-oceanic ridge-rift systems. There are several indications that the upper layers of the oceanic segment of the earth are sinking down in trenches. We suspect that this downward movement may be one of the most important processes in the formation of island arcs, granitic continental masses and both folded and volcanic mountain systems.

Here, the urgent problem is to establish firmly the existence and the speed of sinking of the ocean crust and possibly the upper mantle.

We propose comprehensive international research in selected trench-arc systems, such as those in the Western Pacific Ocean and the Southeastern Pacific Ocean.

The marine investigations of the trenches in these areas should be carried out in close coordination with land investigations of related arc systems. Island and continental arcs, including the arc of South America, are characterized by many notable features, such as zonal distribution, parallel to the axis, of heat flow, seismicity, seismic stresses, upper mantle seismic wave velocity and wave absorption, petrology of volcanic rocks, crustal movements, and deep electrical conductivity anomalies. Fruitful results can be expected only when good cross-sectional studies are made continuously from the ocean-trench-arc to the marginal seas behind the arc, or in the case of the South American Arc, the Andes and the continent behind them.

If the oceanic crust moves slowly toward and under the trenches, the fate of the sedimentary cover overlying the oceanic crustal rocks is of special interest. Are the sediments squeezed and folded against the continents and covered under the slumped materials from the continental slope or do they disappear in the great grinding mills of the trenches?

The origin of the marginal seas, such as the Seas of Japan and Okhotsk and the Caribbean, is a mystery at the moment. The deeper part of these seas has sub-oceanic crust and therefore, if these seas were formed by depression of an ancient continental mass some mechanism of transition of continental crust to oceanic is necessary. Before making a hypothesis about such a mechanism, the real history of the bottom of these seas must be studied thoroughly. Seismic profiling and and deep-drilling should be useful for these studies.

(c) Mediterranean seas

The origin and history of the Mediterranean and similar seas present problems similar to those of the marginal seas. One of these is the often observed low seismic velocity (7.5 km/sec) in the mantle under the crust. For the solution of these problems the distribution of the granitic layer and the continuation of typical continental structures under the sea must be determined.

Because the seas are small, cooperation of relatively small scale between interested nations may prove most effective. Investigations here should be coordinated with those carried out in the surrounding land areas. For instance, comparative studies should be made of the basal series of Alpine geosynclinal formations with those now found under the Mediterranean floor.

(d) Ocean basins

The problem of greatest scientific importance in these areas is to identify the materials that compose the so-called 2nd and 3rd layers above the "Moho" as well as the upper mantle beneath it. The latter may be revealed by finding outcrops of ultrabasic rocks or inclusions of these rocks in basalts.

The possibly anisotropic seismic behavior of the upper mantle may give a significant indication of the paleo and present stress states. The variability or homogeneity of the geophysical properties of the crustal layers from one part of the deep ocean to another is important also. For instance, are there any systematic variations between the areas covered by linear magnetic anomalies and those where there are no such anomalies and which are sometimes supposed to have been formed by sinking of a continental mass? Deep-drilling will be useful in solving these problems.

The horizontal and vertical movements of the deep ocean crust can be investigated by studies of seamounts, guyots, atolls and upraised islands. Combined magnetic and bathymetric surveys of sea mounts can be used to give the paleomagnetic orientation and hence information about the vertical and horizontal movements of the surrounding sea floor.

Deformations and other phenomona near the margins of ocean crustal plates as a result of their motions are of special interest. Bottom topography, seismic activity, deformations of magnetic anomalies, and ancient sediments and igneous rocks from outcrops or drill cores will be useful in studying these deformations.

Investigations should be carried out of possible remnants of ancient rifts, trench-arcs and continents in the ocean basins. These anomalous features may give us information about periods of the oceans' history longer than those that can be studied in the more "normal" areas.

(e) Stable continental margins

Continental margins where there are no trenches or active seismicity are called "stable". The eastern and western margins of the Atlantic Ocean are typical. The eastern margins of the Asiatic continent inside the trench-arc systems also belong to this category.

Studies of the western margin of the Atlantic Ocean have revealed the seaward growth of the continent, the past alternation of erosion and deposition, and the presence of buried folds, faults, unconformities, salt domes and calcareous reefs. Changes of sea-level shown by the topography and in sedimentary strata are good indicators of the vertical movement of the shelf areas. These studies should be extended to other stable continental margins, such as the Eastern Atlantic, Western Pacific, African and Australian margins.

Continental slopes, where ancient strata and igneous rocks are often exposed, present good opportunities for the study of ocean history. In marginal seas such as the Seas of Okhotsk and Japan, the transition from continental to oceanic crust can be investigated by petrographic and geophysical examinations of the sunken continental blocks.

Comparative geophysical studies of trench-arc systems and stable continental margins will reveal the differences in deeper structures and thereby give us insight into why some margins are mobile and some are stable. Differences in subterranean temperature distribution between these regions can be estimated through observations of heat flow and electric conductivity in the boundary areas.

Sources of Sediment Material and Energy for Sedimentary Processes

Nearly the whole sea floor is covered with sediments. Large parts of the continental crust are also formed by marine deposits, either directly recognizable by their content of fossils, or metamorphosed to schists, marbles, gneisses, or granites. The major part of the constituents of recent marine sediments originate partly from the continents, partly from organisms. A smaller amount is added by volcanic activities or comes from outer space. The main trend of sediment transport is from the coast and its river mouths to the deep sea basins. Transport mechanisms include wind, especially in arid zones, surface and bottom currents, interacting in many cases with waves. Sediment transport sometimes goes on nearly continuously, sometimes in dramatic events like turbidity currents. Sliding of big masses on the continental slopes happens more often than was formerly believed. On the outer shelf the sediment distribution often shows a pattern of fossil origin, some ten thousand years old. Old cliffs and beaches, frequently rich in heavy minerals, and old river beds with placer deposits, were drowned by the increasing sea level after the Pleistocene.

The character of the sediments gives much information about the environmental conditions: coarse boulders, sand ripples, scour marks etc. are associated with strong water movements; mud containing much soft organic matter occurs in quiet water. Specific features show arctic, tropical, deltaic or estuarine influences. Most benthic organisms depend on, or react to, the character of the substratum, hence the populations of both sessile invertebrates and demersal fishes are limited to certain kinds of bottom. Detailed morphological, geological and sedimentological maps therefore are not only a must for undersea exploration but also a help for biologists, for the fisherman using trawling nets, and for the geologist who must interpret fossil marine sediments.

The best information about recent and past environments is given by organic remains: shells, tests, and skeletons from plants and animals that lived in certain temperature, salinity, depth and other conditions. Coral reef complexes, a problem of interest to both biologists and geologists, are a well known example of fossil indicators of past environmental conditions.

The thickness of the sediments is widely variable. A single slump after an earthquake can deposit several tens of meters. In vast areas of the deep sea, more than 1,000 years are needed for deposition of 1 cm of sediment. The record from millions of years can be "lost" on rises by erosion. One important problem, therefore, is to determine the rate of inorganic and organic sedimentation. The rate is dependent on many factors: climate and relief on land and in the sea, distance from the sediment source, water movement, biological activity, etc. Isotopic, paleomagnetic and micropaleontological age determinations may be used singly or in combination to measure sedimentation rates. Knowledge of these rates is not only of scientific but also of economic importance. Regions of rapid sedimentation, where soft organic materials tend to be preserved, may be the source beds for petroleum and natural gas. The formation of manganese or phosphorite crusts and nodules, and the preservations of placer deposits can occur where sedimentation is slow or doesn't take place. Erosion of finer material may concentrate these nodules.

As mentioned, the age of the sediments can be determined by geochemical and micropaleontological methods. These methods are the keys to the understanding of the history of the continental margins and the deep sea, as well as the discovery of climatic changes of the ocean waters in the past.

The problems of interaction at the sediment-water interface have many practical applications. Currents and waves transport sand and cause coastal erosion, both of which raise problems for coastal engineering. They sort out heavy minerals such as gold, iron ores, monazite, etc. from the lighter sands. Chemical interaction of seawater and ocean floor or interstitial waters leads to precipitation of sulphides, phosphorite, manganese nodules and crusts and can be a source of nutrient supply. Exhalations from the crust or mantle coming into contact with the sediments and the sea water precipitate different heavy mineral ores, as in the deep Red Sea. Knowledge of the exchange of heat through the sea floor is of importance to both solid earth geophysics and to physical oceanography. The relation between heat flow and near-bottom temperature distribution merits careful study.

Economic Consequences of These Processes

In considering the mineral and fuel resources, we should distinguish between three regions of the sea floor; shelf, slope and rise, and deep sea.

Exploration and some exploitation is already being carried out in the shelf regions . Mining of tin, iron, coal and other substances is conducted in the same types of rock as on the continents. From loose sediments, gravel, sand and calcareous shells provide material for construction industries. Heavy minerals like gold, tin, platinum, magnetite, ilmenite, rutile, zircon, monazite and diamonds are economically recovered by various industries. Geological and geophysical surveys will give us more information about further possibilities. Similar techniques are useful in exploration for oil and gas. For the next decades these fossil fuels certainly will provide the most important economic contribution from the non-living resources of the marine realm. Phosphorite may become interesting in the future, at least in regions far from convenient sources on land.

Because much is already known, and undersea technology is developed for the shelf water depths, scientific geological and geophysical investigations on the shelves will have the most direct and short time economical successes, provided that scientists are allowed to work there.

We know less about the continental slope and rise, and the technical difficulties for exploitation are not mastered as yet. But there are strong reasons for scientific investigations to go ahead of industrial exploitation. It is the most promising frontier area, especially for oil and gas.

Within the deep sea, confirmation is needed of the new hypotheses mentioned above. Wherever the oceanic crust has been formed by sea floor spreading, it is probably useless to look for oil, because the sediments there are too thin or too young. Rising convection currents under the mid-oceanic ridges from the earth's mantle may bring metal ores such as chromite and nickel, often combined with supposedly typical mantle rocks. If the Red Sea is a typical embryonic ridge and rift system, the hot brines there suggest that zinc, copper and lead resources may be found in many places in the great ridges. If the sediments of the Red Sea - in contrast to the mid-oceanic ridges where they are missing - have an important influence on the composition of the brines, there is little likelihood of widespread brine occurrence.

If the sedimentation rate and the bottom water characteristics are the most important factors for the formation of deep sea manganese nodules and their content of nickel, copper, cobalt, etc., the South Pacific is more promising than other ocean floors. This possibility requires careful scientific investigation.

B. PRINCIPAL PROGRAMS OF INVESTIGATION

Up to 1969, only about 20 deep sea drillings, a few hundred dredge samples of solid rocks, and less than 200 seismic reflection profiles across the continental margins had been obtained. Many observational gaps must be filled both for scientific understanding and practical use of the earth beneath the sea.

Principal Methods to Be Used

(a) Underway observations from surface ships

Precision echo-sounding (preferably with narrow-beam and side-scanning equipment), seismic reflection profiling, magnetic surveys; and gravity surveys, all these must be based on accurate position fixing.

(b) Station observations from surface ships

Seismic refraction and reflection profiling, use of bottom seismographs, deep towed magnetometers and echo-sounders, magneto-telluric measurements, bottom gravity and heat flow measurements, coring, drilling, paleomagnetic measurements of oriented core and rock samples, dredging, bottom photography (profiling if possible), bottom television (recorded on tape if possible).

(c) Detailed surveys of limited areas

Grid surveys using methods listed under (a) and (b) with very precise relative positioning (e.g. with anchored buoys and bottom acoustic transmitters), magnetic surveying and oriented sampling of hard rock bottoms (seamounts, ridges, other outcrops), observations and sampling with submersibles.

(d) Airborne magnetic surveys from low-flying aircraft with navigational control from surface ships

(e) Processing

Construction of profiles, charts, compilation of atlases, analysis of samples (acoustic and other physical properties, chemical isotopic, petrographical, micropaleontological).

Program Proposals and Problem Areas

Program 1. Morphological charting of the sea floor
2. Systematic geological and geophysical surveys of continental margins
3. Completion of magnetic survey over the world ocean

4. Deep-drilling at key sites
5. Detailed studies near crests of the ridge-rift system
6. Ocean and land studies of trench-arc systems
7. Investigation of anomalous deep ocean crustal areas
8. Geological and geophysical studies of mediterranean and marginal seas
9. River mouth monitoring
10. Meridional profiles of deep ocean sediments
11. Manganese-nodule resource assays

Program 1

Morphological Charting of the Sea Floor

Scientific aspects: all marine disciplines have a strong interest in detailed charts of the morphology of the sea floor as a basis for further research.

Practical aspects: base charts for offshore exploration for ores, oil, and gas; charts for bottom fisheries.

Methods: echo-sounding (preferably narrow beam and side-scanning). Highly accurate positioning is required (± 100 meters). Continuous seismic profiling and frequent sampling to determine bottom character (whether rocky or covered with fine or coarse sediments) is desirable.

Regions: worldwide, in previously unsurveyed areas starting on the continental shelf and slope, going down to the deep sea. The first 5-years of the project should cover depths down to 3,000 meters.

Scale: The spacing of survey lines depends on the desired chart scale. In critical areas for fisheries, a scale of less than 1 to 100,000 is needed, requiring survey lines on a spacing of about 0.5 km or less. In many areas a chart scale of 1 to 1,000,000 will be sufficient, with survey lines about 5 km apart. Fairly satisfactory charts on a scale of 1 to 1,000,000 can be made with a spacing of 10-15 km between survey lines.

Program 2

Systematic Geological and Geophysical Surveys of Continental Margins

Scientific aspects: Better understanding of sedimentary, igneous and metamorphic crustal structures under the sea floor in the transition region from oceans to continents and the geophysical characteristics of the underlying mantle. Processes of sediment transport from the coast to the deep sea. Distribution of benthic organisms with depth and latitude. Plio-pleistocene sea levels and eustatic and tectonic changes in sea level from evidence of relic beaches, terraces and coral reefs.

Practical aspects: Reconnaissance surveys to find location and extent of thick sedimentary basins and structures for possible oil and gas accumulations; discovery of phosphorite deposits on the outer shelf, and placer and beach deposits and other minerals on both the inner and outer shelf; delineation of rock structures with mineral and fuel resources continuing from the continent. Sediment maps for fisheries.

Methods: Reconnaissance survey, using underway and station observations, of the entire marginal area. Additional geological and hydrographic investigations of key areas, such as those having arctic, humid, arid or tropical hinterlands with and without high relief, areas off river mouths, and regions where there are prolongations of great tectonic trends from the continent to its margin.

Priority regions:

1) East Atlantic continental margins from Novaya Zemlya to Cape Town
2) Continental margins around Central and South America
3) Pacific continental margins of Southeast Asia
4) Continental margins around the Indian Ocean

Program 3

Completion of Magnetic Survey Over the World Ocean

Scientific aspects: delineation of areas with and without magnetic lineations. Detailed magnetic mapping of areas with lineations, especially in axial zones of rift systems.

Practical aspects: basic information for geomagnetic navigation, possible magnetic ore resources in the sea bed.

Methods:

1) reconnaissance air-borne survey by low flying aircraft with navigational control by surface ships

2) detailed ship-borne surveys using surface and deep-towed magnetometers combined with bathymetric, seismic reflection profiling and gravity measurements, in areas of special interest, such as boundaries between oceanic plates and central parts of ridge systems.

Regions: worldwide in unsurveyed areas.

Program 4

Deep Drilling at Key Sites

Scientific aspects: an order-of-magnitude increase in understanding of the history of the ocean floor through petrological, chemical and paleontological identification and determination of age of constituents of subbottom layers in continental margins, mediterranean and marginal seas, and the deep oceans; determination of physical properties and ages of different layers as keys for the interpretation of seismic reflection profiles; and measurements of paleomagnetism in core samples.

Practical aspects: reconnaissance information on possible non-living resources under the ocean bed, for example, oil traces on a Sigsbee Knoll.

Methods: for the open ocean and mediterranean and marginal seas, special drilling vessels will be required and at least two additional vessels besides the present one should be fitted out and put into operation. For the continental margins it should be possible to use present exploratory drilling ships and especially fitted oceanographic ships. New techniques need to be developed for drilling from oceanographic ships as well as for drilling of shallow and deep holes in hard rock, and for deeper penetration into the Earth's crust. Some key sites should be the center of a detailed grid area for geophysical investigations; in others, reconnaissance station observations should be sufficient.

Regions: the objective should be to drill 200 to 400 deep holes during the next ten years with about one-third in the mediterranean and marginal seas, and one-third in the deep ocean. Selection of actual sites will depend on questions raised in the course of other geological and geophysical investigations.

Program 5

Detailed Investigations Near the Crests of the Ridge-rift Systems

Scientific aspects: determination of the mode of extrusion, spatial relationship, relative age, composition and magnetic properties, of basalts, serpentinites and ultra basic rocks forced up from the earth's interior (probably from deep within the mantle) to the sea floor along the crest and rifts of mid-ocean ridges. In areas of sea floor spreading, these rocks, after coming to the surface, are believed to move laterally away from the ridge axis at a speed of about 2 cm per year, forming the striped magnetic pattern which characterizes large areas of the sea floor.

Practical aspects: location and extent of possibly valuable metallic ores in the serpentinites and ultra basic rocks exposed near the axis of the mid-ocean ridge-rift system. Greater understanding will also be obtained of the properties of the mantle rocks that are believed to be the source of many metallic ores on land.

Methods: surface ship underway, station, and detailed grid observations with precise relative position fixing; refraction and reflection seismic profiles; use of towed magnetometers and echo-sounders; underway gravity measurements; collection of short, oriented drill cores or rock for magnetic, chemical, petrographic and physical analysis; underwater photography, measurement of heat flow where practicable.

Priority regions:

1) two areas of 1 to 3 square degrees on or near the axis of the mid Atlantic Ridge, one between 40-60°N and one between 20-40°S.
2) two areas of similar size on the East Pacific Rise off Central and South America.
3) two areas of the Mid-Indian Ocean Ridge.

Program 6

Ocean and Land Studies of Trench-arc Systems

Scientific aspects: determination of the relationships between the apparent downward movement of ocean sediments, rocky crust, and possibly the upper mantle under the trenches, and the formation and growth of island or continental arc structures, their associated volcanoes and marginal seas or lowlands. New light should also be shed on the recycling of water, carbon dioxide, dissolved salts, and sedimentary materials and possibly of crustal and upper mantle rocks in the zone of downward movement.

Practical aspects: knowledge useful for earthquake prediction in these seismically hyperactive regions may be obtained, together with greater understanding of the sources and mode of emplacement of ore bodies along island arcs and continental margins, and the formation of sedimentary structures which may act as reservoirs for oil and natural gas.

Methods: all the methods outlined under B are applicable for the trench and marginal sea areas. In addition, coordinated geological seismic and other geophysical studies should be conducted on the land areas of the trench-arc system.

Regions: (all of about equal priority)

1) South American Trench-Andean arc system on both sides of the equator.
2) Oceanic island-arc systems such as the Tonga-Kermadec or Aleutian island area.
3) Japan-Kurile trench-island arc-marginal sea system.

Program 7

Investigations of Anomalous Deep Ocean Crustal Areas

Scientific aspects: some deep-ocean crustal areas may have a different origin or history than those apparently formed by relatively recent sea floor spreading. For example, the areas between Africa and the Seychelles, off Western Australia, and northeast of New Guinea may be submerged continental remnants, while the crust under the Philippine Sea may have been formed of materials extruded from a ridge that has now disappeared.

Practical aspects: if old continental rocks exist in some of these areas, the geologic section may be quite different than in the "typical" ocean crust, and may contain resources that could be useful in the future.

Methods: seismic and other geophysical methods should be used to elucidate the character of the crustal anomalies in these regions.

Priority regions:
1) Western Indian Ocean between the Seychelles and Africa
2) Eastern Indian Ocean off Australia
3) Western Pacific north and east of New Guinea
4) Philippine Sea

Program 8

Geological and Geophysical Studies of Mediterranean and Marginal Seas

Scientific aspects: origin and history of mediterranean and marginal seas and their relations to major geological events on land, such as the Alpine orogeny and the formation of the African Rift Valley; structure and properties of the crust and upper mantle beneath these seas; sedimentation in relation to morphology and hydrography; distribution of benthic organisms; terraces indicating Plio-pleistocene sea levels.

Practical aspects: reconnaissance surveys for possible structures which could be reservoirs for oil and gas and rock structures that might contain mineral resources.

Methods: see B, (a) thru (e).

Priority regions:
1) Mediterranean Sea
2) Japan and Okhotsk Seas
3) East Indian Seas from Philippines to India
4) Red Sea (also a ridge-rift problem)
5) Gulf of Mexico - Caribbean Sea

Program 9

River Mouth Monitoring

Scientific aspects: determination of the supply of sediments and dissolved materials from the land to the oceans.

Practical aspects: off rivers such as the Nile and the Indus, where river transport of both dissolved and solid material is being drastically changed by man's activities, marked alterations in the biological regime of the nearby ocean waters may occur as well as destructive erosion and other shoreline changes. These represent serious problems both for fisheries and for coastal engineering. For other rivers, pesticides, excess nutrients and other pollutants are entering estuaries and the open sea in potentially dangerous quantities.

Methods: installation of, or cooperation with, existing observation stations near river mouths in different climatic and morphological regions; arctic, tropical, humid, arid, with mountainous or low hinterlands.

Standardized continuing measurements of water supply, temperature, pH, content of carbonates, Na, K, Mg, Ca, SO_4, Cl, important trace elements, nutrients, pollutants, suspended particles, especially organic and clay minerals, bed load, interaction with tides.

Regions: worldwide.

Program 10

Meridional Profiles of Deep Ocean Sediments

Scientific aspects: relations between oceanic and atmospheric climates on a geological time scale and the sediment characteristics, geochemistry and micropaleontology of sediments. Determination of paleo-climatic changes in water and the atmosphere from evidence in core materials.

Practical aspects: greater understanding of the present and past world climates and of the interactions among climatic zones in the atmosphere and the ocean, and hence of the dynamics of climate.

Methods: collection of long cores (preferably oriented for paleomagnetism) and bottom photography from surface ships; chemical, petrographic and micropaleontological analysis of core samples.

Regions: Atlantic, Indian, Pacific Oceans.

Program 11

Manganese Nodule Resource Assays

Scientific aspects: origin, distribution and composition of manganese nodules, interaction between bottom water and sea floor.

Practical aspects: quantity, distribution pattern and size of manganese nodules together with their content of nickel, copper, cobalt, chromium, molybdunum, and manganese.

Methods: detailed grid survey using precision echo-sounding, bottom photography, dredging of large bottom surface samples, sediment coring, chemical analysis of nodules.

Regions: three selected deep sea areas of about 1 square degree.

IMPLEMENTATION OF AN EXPANDED PROGRAM

We were aware that simultaneously with our consideration of the scientific content of an expanded program, and of several closely related question, others have been concerned with the development of the necessary inter-governmental machinery within the UN system, in which a suitable broadened IOC will play an important role, and with the full participation of other organizations of the UN system and others. Through this machinery, such a program would be planned in detail and its implementation coordinated. It will be clear that, while some parts of the suggested scientific content are more ready for development that are others, all will require adjustment in the light of national programs to be proposed, and to be more fully elaborated and evaluated as to costs, facilities and scientific and technical manpower requirements. This elaboration will require the continued participation of a large number of scientists, especially in the first years, mainly through specialist and inter-disciplinary working groups, at both national and international levels, but also through symposia to review difficult or controversial matters from time to time. Furthermore, even during the decade there will surely be considerable shifts in emphasis; some projects may be modified, new project ideas will emerge, and technical developments may drastically change research costs. Scientific groups, some like the present one, very broadly inter-disciplinary in character, should therefore be called upon to evaluate on a continuing basis the implementation of the program as it unfolds and to assist in ensuring the rapid and wide dissemination and application of results to peaceful purposes. This will require improved organization of marine scientists through international non-governmental organizations, a wider participation in these of all disciplinary groups including some at present somewhat apart - for example ocean engineers - and the continued support of such activities by the intergovernmental organizations concerned. It will be particularly important to assist the active participation in the work of these organizations by scientists from the developing countries, as well as their access to adequate modern facilities for studies.

Implementation of the expanded program will thus call for improved organization, additional laboratories, platforms and other facilities for research; further development of methods and instruments and the inter-calibration and standardization of some of these; expansion and development of storage and retrieval capability for data, samples and documents and a greatly increased effort to interest scientists and technicians in the marine field, and to train them.

The group discussed at some length the question of how to facilitate a broad and equitable participation in the expanded program by many countries large and small, and particularly in large scale interdisciplinary projects. Several suggestions were put forward and are summarized here as a basis for further study of their merits and feasibility. Success in this aim will probably come from a combination of such suggestions.

The scale and wide scope of many projects proposed in this report will require the marshalling of facilities now available to few, if any existing research institutions. In some cases groups of institutions will undoubtedly act in association to carry out major projects; their individual programs of research and teaching may have to be modified in consequence. National institutions might be expanded in such a way as to fulfill specific international functions. Again, existing international organizations, world wide and regional, may be strengthened, and bilateral and multilateral mutual aid arrangements made between certain of the more advanced and developing countries.

Another idea which received some support was that of developing an international oceanographic center or centers comprising a laboratory devoted to the conduct of large scale surveys, the development of complex technology and the operation of sophisticated facilities and an associated "work shop" to conduct seminars and advanced training for scientists and technicians. This might require international joint funding by interested governments and organizations.

Facilities

In the following paragraphs, an attempt is made to summarize a first estimate of the facilities required for complete implementation of all the various projects proposed in the report. It should be noted that many of the projects are extensions of work that is already underway or has already been programed, both in developed and developing countries. On the other hand, it is clear that a new level of effort is required if the expectations of the expanded program are to be met. This indicative list of the relative magnitude of facility requirements, which includes perhaps an equal part of existing and new facilities, is very preliminary because at the present early stage of program formulation, reliable logistic calculations cannot be made. In our view, some of the following estimates are probably conservative, and even greater facilities may be required if rapid progress is to be made in achieving the purpose of the expanded program.

A Ships and other equipment for work at sea

(a) Surface Ships

(i) Survey ships: To obtain the data for morphological charts of the world ocean during the next twenty years would require the steady operation of about twenty-five vessels.

(ii) Research ships: For the proposed programs in air-sea interaction, ocean circulation, dynamics of the ocean floor and biological production perhaps forty major research ships would be used essentially full-time during the next ten years. Half of these might be equipped for stern trawling, acoustic gear for locating, identifying and tracing swimming animals, and other fishery research gear.

(iii) Fishing vessels for systematic resource evaluation: At least 20 additional ships capable of operating under a wide range of ocean and weather conditions might be required for the next ten years.

(iv) Weather ships: Eight weather stations are occupied in the Atlantic by about 25 vessels; all of these would need to be equipped with oceanographic apparatus and a laboratory. The same considerations apply to the four ocean weather stations being operated in the North Pacific.

(v) Aircraft carrier and escorts for magnetic surveys: A small aircraft carrier with a complement of six or more propeller driven aircraft, each equipped with a recording total-field-intensity magnetometer and capable of flying at altitudes of 600 meters or less would be needed through the next decade.

Two escort ships with cruising speeds equal to that of the aircraft carrier, equipped with precision radar for tracking the magnetometer aircraft, recording echo-sounders and accurate navigational equipment, would be needed.

(vi) Deep sea drilling vessels: Three ships with capability equal to that of GLOMAR CHALLENGER for accurate positioning, drilling in depths up to 5,000 meters, and eventually for hole re-entry, would be needed for about 5 years.

(vii) Continental shelf and upper slope drilling vessels: It may be possible to equip some of the research ships listed under (ii) for this task; otherwise five or more drilling barges of types now used by oil companies would be required for about 5 years.

(viii) Ships of opportunity: In addition to the 100 or so ships of opportunity, equipped for upper air and bathythermograph observations, foreseen for the World Weather Watch, about 50 merchant and naval ships and an equal number of fishing vessels should be equipped with apparatus for temperature measurements through the mixed layer, plankton recorders and other routine continuous recording gear. These vessels should be carefully selected for areas of operation, interest and capability of officers and crew, radio communications and navigational capability.

(b) Submarines and small submersibles

(i) Nuclear powered submarine: One nuclear powered submarine with long cruising radius would be needed for one or two six-month cruises to study the formation of deep water in the Weddell Sea.

(ii) Small submersibles: Four small self-propelled, manned vessels with depth capabilities ranging from 300 to several thousand meters would be valuable for several programs of biological and sea floor studies. Each of these vessels could be usefully occupied for several years; they will require accompanying logistic support ships.

(c) Buoys

(i) Anchored buoys: Several hundred deep sea anchored buoys, fully instrumented for meteorological and sub-surface oceanographic measurements, recording over time periods of weeks to months, and radio telemetering, would be required for the IGOSS and related programs. Appropriate buoy tenders will also be required.

(ii) Drifting buoys: Some 700 freely drifting buoys are planned for the GARP program. Some of these, perhaps 100, should be fitted with recording current measuring apparatus and possibly other oceanographic instruments.

(d) Precision navigational system

All the surface ships referred to above should be capable of precisely fixing their position within $\pm$ 200 meters. This could probably be accomplished by combined satellite and long-wave radio navigation system with suitable equipment provided for each vessel.

(e) Radio communications system

Telemetering of oceanographic information from all ships and buoys should be possible, perhaps in some cases using a satellite radio link.

(f) Satellite instrumentation

Earth-viewing satellites should be equipped for sensing temperature at and near the sea surface, and other surface and near surface ocean properties (see reference below to development of new techniques).

(g) Fixed monitoring stations

(i) River mouth stations: Stations equipped for sampling water, organisms, and sediments and for making temperature, current, water and sediment transport, and other measurements would be needed at or near the mouths of all major rivers.

(ii) Near shore stations: Recording stations for temperature and other atmospheric and oceanographic parameters would be needed on many oceanic islands and on various points on continental shores. Development of stations that could be left unattended for long periods is needed.

(h) Improved instruments and methods

(i) Echo-sounding gear: Recording echo-sounders should be improved by mounting them on stablized platforms and narrowing the beam to no more than a total width of 5°.

(ii) Deep towed or self-propelled instrument packages: Magnetic, gravity and echo-sounding instruments towed or freely moving near the bottom can give unique information not obtained by remote measurements from the surface. Towed instruments at mid-depths can be used to study stratification of the water and the currents at various depths.

(iii) Free instruments: Bottom seismographs, pressure recorders, current meters, fish traps, sediment traps, and recording cameras which must be operated on the sea floor continuously for as long as possible should be capable of release from surface ships during the period of operation and then be returned to the surface for recovery on demand. Various kinds of mid-water floating instruments for measuring internal waves, currents, turbulence, and possibly for biological observations should be further developed.

(iv) Acoustic and optical gear for fishery research: The resolving power of acoustic methods for locating, identifying and observing the behavior of swimming and bottom living fish and invertebrates is already being improved, but development should be accelerated. Optical methods, possibly using lasers to increase the seeing distance, should be explored.

(v) Drilling equipment: Three development problems are paramount: a method of hole re-entry which would enable greater penetration of hard rocks encountered in deep drilling; taking of short oriented cores from rock outcrops; relatively lightweight drilling equipment which can be used from oceanographic research ships.

(vi) Satellite instrumentation: Sensors are required for measurement of sea surface conditions, if possible regardless of cloud cover; conditions of interest include temperature, sea state, height of sea surface (with precise altimetry), presence of pollutants, and chlorophyll concentration.

(i) Heavily-instrumented ocean station

An island station or other platform should be established where various experimental combinations and array arrangements of subsurface instruments could be tried to obtain integrated information on ocean structure and motions in three dimensions.

B Shore facilities

In ocean research much more scientific time must be spent ashore than at sea. But the objectives and rationale of research and development in shore laboratories, shops, and offices should be focussed on equipment developments, experiments, analyses, computations, and construction of theoretical models which are closely related to events in the real ocean and to observations and measurements in the sea. Many kinds of shore facilities can often be more effective if they are combined at one location, although for reasons of convenience, unique environmental conditions, and limited support it may be necessary to operate some facilities separately. Implementation of the expanded program will require strengthening of existing shore facilities and addition of new facilities in appropriate places.

(a) Research laboratories

Shore laboratories for studies of the genetics, physiology, behavior, life histories, nutrient requirements, and energy utilization of marine organisms, are essential for greater understanding of biological production in the oceans. Similarly, laboratories are necessary for research in all other aspects of ocean research and engineering.

(b) Sorting centers

Measurements of the distribution and quality of eggs and larvae and of associated zooplankton depend on separation and counting of the different components of biological samples, or other assay methods. Adequately staffed international and national sorting centers for each major ocean region will be needed.

(c) Analysis centers for pollutant and other monitoring programs

Regional laboratories for analysis of pollutants and other materials carried to the ocean by rivers and through the air should be established or designated and provided with adequate support.

(d) Standardization and test facilities

One or more shore facilities with good access to the open ocean should be established for intercalibration and standardization of chemical and biological methods, and comparative testing of current and other measuring instruments.

(e) Data centers

These are considered below.

(f) Chart production

Much more effort should be given to production and distribution of accurate and easily used charts of bottom topography and bottom character at appropriate scales.

Training and Education of Specialists

The United Nations Report on Marine Science and Technology emphasises that "the scarcity of competent personnel still remains a limiting factor to the development of national efforts and of international cooperation". Thus any substantial expansion of marine research implies a commensurate strengthening of scientific and technical staffs, but the magnitude of the requirement cannot be specified until the expanded program is more fully developed. It is clear, however, that the process of education is time consuming and that an early start is essential.

It is also still early to predict the relative demands for specialists in the very wide range of basic scientific disciplines as well as engineering skills now involved in the investigations of the ocean and its resources. There seems to be a relative weakness in most fields, particularly in the developing countries, but the demands will vary from country to country according to its development expectations. A new requirement for specialized manpower is being placed by the growth of ocean-based industry.

In general, the overall requirement is for people to be educated in a specific discipline, to be given special training in its marine aspects, and because of the interdisciplinary nature of so many ocean problems, to be imbued with a broad understanding of the other disciplines involved, especially in their marine applications.

In the report referred to, general proposals were made for the kinds of necessary strengthening of educational and training programs, and the ACMRR and the IOC Working Group on this subject have made more specific proposals. In the present study, the need for such strengthening was confirmed; what is needed are considerably more funds for these purposes and better arrangements for coordination.

The declaration of the expanded and long-term program itself should arouse interest in young people being trained in the natural sciences, although special efforts will be needed to create an awareness of the scope of the proposed program in the teaching institutions. The supply of marine scientists and research technicians especially in the developing countries will be limited by the total output of graduates, and of people with suitable secondary technical education, but the translation of interest into real growth will depend to a great extent on career opportunities.

It will be necessary to include more reference to marine problems in the natural science curricula, but beyond that is foreseen a greater need for more specialized education at the graduate level. This will strain existing teaching facilities. There is no unique solution to the problem. Not only must universities and laboratories in more advanced countries be prepared to accept increased numbers of students from overseas, but in the developing countries it will be necessary to set up, often on a regional basis, specialized teaching arrangements. An important contribution to this latter would be the endowment through international and bilateral development funds of teaching posts in selected educational institutions; such endowments would need in each case to be accompanied by research grants or other arrangements made to ensure that teaching is firmly based in research practice.

Advanced post-graduate training can be expanded through fellowships, but many of these need to be of longer term than have up to now been provided by international agencies. Such a program should be extended to cover also study grants for experienced research workers in all participating countries to work for periods at other laboratories, both to give others the benefits of their skills and experience, and to learn themselves new techniques developed elsewhere.

Through the expanded program there will arise many opportunities for scientists and technicians from countries bordering the particular study areas to take part in cruises of research vessels from neighboring and distant countries; there needs to be a greatly increased provision of travel grants and short-term fellowships, flexibly administered, so that these opportunities can be grasped. If, as has been proposed, a special IOC fellowship scheme is established and if it is adequately financed, one of its most important functions would be to permit such exchange in connection with the cooperative investigations foreseen in expanded programs.

There is already a need, which will become more acute, for a central register of fellowship opportunities and education and training facilities. This will require adequate secretariat support to make exchange of such information rapid, comprehensive and effective. It should not be difficult to achieve, particularly if the proposal for joint planning and conduct of the UNESCO and FAO programs is implemented.

To carry out particular projects within the expanded program there will be a need for many short training courses in the methods to be used. Such courses will be needed as much for technical staff as for research workers. In fact much more attention needs to be given to the specialized training of technicians in many sides of marine work; this is perhaps most important in those developing countries which have already established small research nuclei, but are still, and may remain for some time, critically short of graduates in the natural sciences.

The land-based support units - data and biological sorting centers, instrumentation groups and so on - called for by various projects, will all create special training opportunities which must be fully exploited. From the work of such groups would emerge methodological manuals which will provide texts and other teaching material, at present sadly lacking in many areas of marine science. In this connection it seems most desirable to enlist the aid of organizations, and institutions specialized in the evolution of improved teaching methods in science generally to help raise more rapidly the output and quality of training in the marine field.

We endorse the view that expansion of specialized libraries and, generally, of the coverage, scale and continuity of scientific documentation and related services for marine scientists is an essential element in an improved education and training program.

Methods of Measurement

Methods for the scientific investigation of the ocean have been developed during the past hundred years. A few of these methods have been sufficiently perfected for standardization to be possible (as in the determination of salinity). In other cases, imperfect but reasonably satisfactory methods are available and can be compared with a standard in a procedure of intercalibration (for example, estimation of primary production by the C^{14} method). In many cases, methods are in a state of rapid evolution, and the results of measurements by different techniques cannot be easily compared (as is the case with measurements of current velocity or of light transmission).

In cooperative investigations, it must be possible to pool results regardless of origin. This is particularly difficult when many laboratories in a number of countries are involved. Therefore, as part of the expanded program, there is required an intensive effort on improvement of methods and on their intercomparison. The perfection of methods is the work of individual scientists and laboratories. Internationally, these efforts are being coordinated by non-governmental organizations, such as SCOR, and by intergovernmental bodies such as IOC, FAO (and its ACMRR), WMO, ICES, etc. Intensification of the effort requires the cooperation of scientists and the governments that support their work; strengthening of the coordinating mechanism may also be necessary. As satisfactory methods are perfected they must be used as widely as possible and international action may be required to make the necessary equipment available and to arrange for instruction in its use.

Information and Data Exchange

Ocean science is not alone in being overwhelmed by the flood of information and data resulting from present programs. The problem is general throughout science and is being studied intensively by national and international bodies. One result of an expanded program will be an intensification of this problem.

At present, a thorough literature search on an oceanographic question may require examination of a number of bibliographic publications of varying scope and approach. The very breadth and interdisciplinary character of ocean research make this so. Ultimately marine scientists may be served best by the development of a general World Science Information System, as is now being studied by ICSU and UNESCO, rather than by the perfection of a specialized ocean system. The relative advantages, and costs and organizational problems of these two approaches should be examined. In the interim, however, the scientific program to be carried out during the expanded program will benefit considerably from improvement in, and coordination of, present ocean-oriented services, which in any case will need to expand with the information flow.

The information problem also involves the early exchange of planning information and preliminary results in cases where the coordination or implementation of research could be benefitted. Collection and compilation of such early information will require the active interaction of an international staff and the laboratories concerned. It seems likely that within a short time, the cost of this service would be outweighed by the savings in the cost of research.

Scientific data, because of their large volume and diversity, present special difficulties. Valiant efforts have been made in national, regional and world oceanographic data centers to improve the handling of ocean data, but the present system is barely able to cope with the storage and retrieval of classical oceanographic data on a historical basis and is presently incapable of handling any data on a real-time basis (unlike the situation in meteorology), or of handling certain new types of data, and biological or geological data. The increased volume of data resulting from an expanded program will obviously compound these difficulties.

The real-time exchange of ocean data is provided for in plans for the Integrated Global Ocean Station System (IGOSS). It seems inevitable that the real-time transmission, analysis and forecasting of ocean data and of meteorological data should be linked in a common system. This will impose an increased load on the meteorological system, but the alternative of developing a separate system for ocean data appears economically impracticable and scientifically undesirable.

For ocean data that do not require real-time transmission, it is necessary to arrange for the prompt transmittal of data in computer-compatible form. Computer programs must be developed for the analysis and retrieval of these data in a variety of forms. Methods for handling biological and geological data must be developed, and special arrangements will be needed for handling the information coming from the proposed pollution monitoring system, possibly by expansions of one or more existing centers within the World Data Center System. Since a modern data center must have a significant computer capability, it is likely that one or more national data centers will have to be suitably strengthened to perform this service for the international community.

There is a need for rapid access to vast and growing quantities of data in archives, and ways of presenting it in summary graphic form to a subscriber anywhere in the world as he requests it. Portable consoles which can connect very simply via long-distance public telephone and which can then extract data from the main archive by computer have already been developed, and newly designed computers with vast memory, make possible extremely rapid display of holdings of data now in national oceanographic data centers. Such equipment will make it possible for a subscriber to obtain charts made up from any combination of the total data holdings of a center simply by one relatively brief long-distance telephone call. A program language for linking the central computer to the telephone system is presently being written. Although this will make available all existing archived hydrographic data in a versatile way, it will not include such important data as in situ salinometer and temperature records. The possibility of extending the concept to include many other forms of data will need to be explored.

Non-digital data of several kinds pose special storage and retrieval problems which must be solved; examples are photographic records of the sea-bed and its inhabitants, and other environmental features; acoustic records of the deep scattering layer and of other concentrations of organisms; biological data and materials of many kinds. A facility of growing importance will be international centers, of the type already envisaged in the FAO Fishery Data Center, which while they may hold some original records, will essentially catalogue and provide a key to data, or to biological and geological samples and bottom photographs held elsewhere in national institutions. Another type of facility which has appeared in recent years and which will need to expand, especially in relation to the biological, and perhaps the geological projects, is the sorting center which has some of the features of the research departments of museums, and some of the data centers, but which is mainly concerned to provide the service of approximate identification and counting of samples as a stage in their detailed processing. Through such centers the skills of a very wide range of specialists are marshalled and they also provide an extremely valuable opportunity for training of technicians.

Such services rely heavily on continuation of work in other key fields of science, such as biological systematics, which are not mentioned elsewhere in this report and interest in which has in some cases declined in recent years in an alarming fashion.

SUMMARY

The questions posed by the Bureau of the Intergovernmental Oceanographic Commission provide a convenient framework for a summary of the working party's conclusions. These conclusions have not been framed as formal recommendations because of the preliminary nature of the present exercise, which must be considered as only the first step in the planning of an expanded and long-term program.

What are the most important oceanic research problems that should receive particular attention in the near future?

In each field of marine research considered by the working party, a number of the most important oceanic research problems have been identified as meriting attention during the next decade. In some cases, only the first steps can be taken in that period, whereas other problems appear to be capable of near-solution in the near future. Briefly, the problems mentioned in the program chapters are as follows:

Ocean circulation and ocean-atmosphere interaction

The air and the sea together form a vast heat engine on which our weather and climate largely depend, and a major air is the development of an ocean-atmosphere prediction model of global application. It is necessary to assess the feasibility of such a model by developing quantitative predictive techniques on problems of more limited scope. Measurements are required to improve understanding of large-scale, long-period fluctuations in and over ocean basins such as the North Pacific. Transient phenomena such as the annual reversal of circulation associated with the monsoons require investigation. An improved picture of seasonal and year-to-year variations in the sea-surface circulation and characteristics should be developed. Little known circulations on both the eastern and western sides of oceans need to be more completely described and appropriate models developed. Oceanic processes such as the anomalous accumulation of heat in tropical regions and the consequences for tropical storms require investigation. Knowledge of the scales and frequencies of ocean variation and the associated velocity spectra is needed before an effective monitoring network can be designed. Understanding of the process of coastal upwelling requires both theoretical and observational studies and is linked with the broader ocean-atmosphere interaction. The processes and rates of forming intermediate and deep water masses and their subsequent circulation require elucidation. Development of new techniques for sensing and analysing ocean phenomena is needed.

Life in the ocean

In order to assess possible world production, both of familiar and of less familiar and lower trophic level species, it is necessary to know much more about the global distribution, magnitude and seasonal variation in primary and herbivore production, as a basis for the prediction at higher trophic levels, both locally and regionally. As fisheries expand to harvest a broader range of species, much more information is needed on the distribution and abundance of all primary and secondary carnivores. Not all ecological interactions, however, culminate at the same trophic level and emphasis must be given to understanding appropriate ecosystems, and, for this, the abundance of organisms of each size in each trophic level should be determined. In selected zones of high productivity, the flow of energy and material through the various trophic levels to both the pelagic and benthic communities should be evaluated. It is of particular interest for the next stage in fishery development to gain understanding of the productivity characteristics of herbivores and small carnivores that are found in large concentrations and may become susceptible to harvesting. So far we have been concerned in harvesting natural resources, but processes of concentration and enrichment involved in the production of coastal waters should also be studied with a view to establishing a basis for development of coastal aquaculture.

For the rational arrangement of international fishing in the future the effect on recruitment of different levels of fishing and of changes in the environment should also be investigated. This investigation involves the relation between the timing of spawning and the cycle of production, and the modification of this process by long-term processes in the physical environment and by variations in the density of the stock itself. Models should be constructed of the processes that determine density dependence and of the processes that determine year class strength independent of density. As these models are tested, relevant laboratory experiments will be required. It will also be necessary to estimate density dependent mortality at sea. Detailed studies of the various mechanisms by which variations in the physical environment are linked with those at all levels of the biosphere are required as a basis for modelling and prediction. Lastly, new methods and instruments are needed for problems such as detecting fish and shellfish under certain special circumstances, measuring the input of organic material to the sea bed, and observing the behavior of individuals and groups of fishes, including their reactions to fishing gears.

Marine pollution

Dramatic instances have drawn our attention to the extent and dangers of pollution; many of the scientific problems related to the distribution of pollutants within the ocean are essentially the same as those for natural substances, and are treated in other sections. These problems include the physical processes of advection and diffusion, biological processes of concentration and transfer through the food web, and chemical and geological processes acting at the land-water and water-sediment interfaces. In order to control present and anticipated future pollution each substance added deliberately or accidentally to the ocean must be examined to see if it has deleterious effects and if monitoring is necessary and possible. Particular attention is given to the development of a worldwide system of pollution monitoring at vital points in the atmosphere, rivers, ocean and in the ocean biota. Both criteria and methods for monitoring must be developed. The use of pollutants as tracers may contribute to the solution of problems in several fields of marine science. Similarly, monitoring systems necessary for research proper and for pollution studies and control have much in common.

Dynamics of the ocean floor

If we are to exploit the mineral resources of our planet thoroughly from both the sea as well as on land, one of the first problems is to gain understanding of the dynamics of the crust and mantle in the principal tectonic systems of the ocean. This requires investigation of the physio chemical mechanisms of ascent through rift zones and descent through trench-arc zones of materials and energy from the earth's interior. The development of various qualitative models of sea floor structure and origin has been fruitful in recent years, but further critical observations are required to test and refine these models. The nature, structure and thickness of the several layers between the ocean floor and the mantle must be ascertained. Investigations of sedimentation processes require knowledge of the sources of sediment material and energy. Water-sediment interaction is both a geological and a biological problem. Sedimentation rates in various regions of the ocean should be determined, and the processes affecting these rates should be more thoroughly understood. A more complete and precise charting of the shape and character of the sea bed is required for solution of these and of other important ocean problems.

What types of research programs can best contribute to solving these problems?

Examples of appropriate research programs were selected by the discussion groups. These programs vary widely in scope, but each was considered relevant to solution of the types of research problems discussed above.

Ocean circulation and ocean-atmosphere interaction

1. Increase collection and rapid dissemination of synoptic data concerning the surface layer of the ocean, for both operational and investigational purposes.

2. Develop a long-term plan for systematic observation of the North Pacific Ocean, including near surface observations, surveys of the Pacific Gyre, and oceanographic participation in the tropical air-sea interaction experiment of GARP.

3. Study of coastal upwelling, through development and application of theoretical models in selected regions where abundant data can be obtained, and descriptive study of little-known eastern boundary current systems.

4. Investigate the time and space variations of the ocean-atmosphere environment in the monsoon regime of the Arabian Sea.

5. Multiple-ship surveys to describe the Brazil Current and the underlying system of intermediate and deep undercurrents.

6. Establish international ocean observatories where heavily instrumented arrays of sensors and other new measuring techniques for study of shorter period phenomena (dynamics of the thermocline, internal waves, etc.) can be designed, constructed, installed and operated.

7. Measure the distribution of geochemical tracers on densely sampled vertical sections across major ocean basins.

8. Pilot studies from buoys to ascertain statistical information on the space-time variations of surface layer properties, especially velocity, to establish sampling requirements for ocean monitoring systems.

9. Utilize drifting platforms proposed for GARP as devices for gaining additional information on the large-scale features of surface ocean circulation.

10. Use merchant and weather ships in the North Atlantic, equipped with underway and expendable devices, to gather additional information on space-time variations in the physical environment and their relation to planktonic changes.

11. Study the mechanisms of formation of deep water masses with recording buoy systems.

Life in the ocean

1. Measure the rate of carbon fixation and the biomass of herbivores throughout the world ocean, at various seasons and with accompanying environmental information. Herbivore production can then be estimated after suitable laboratory determination of generation time.

2. Conduct systematic exploratory surveys in selected productive regions, using acoustic and exploratory fishing techniques, to determine the presence and concentration of animals of fishable sizes.

3. Conduct a cooperative survey of the living resources of the Antarctic seas and study their environment.

4. Investigate the basic structure and functioning of the ecosystem in at least one area subject to minor exploitation and another subject to moderate to high rates of exploitation.

5. Identify on the basis of environmental characteristics, and survey, potential coastal aquaculture areas on a world-wide basis and select suitable species for culture there, with a view to optimum utilization and improvement of the living resources, and as a step toward mariculture on a broader scale.

6. Carry out investigations in selected areas of the ecology of cultured organisms and of their environments, including their requirements for water "quality".

7. Studies of the stock and recruitment problem, including construction of models of processes determining year class strength, laboratory experiments for improving these models, and estimation of density-dependent mortality at sea.

Marine pollution

1. Establish a world-wide system of pollution monitoring. Develop suitable techniques for measuring various pollutants and select suitable marine test animals and ecological base lines to identify trends. Collect samples at selected locations from both ocean and atmosphere and from the biota. Identify or establish centers for analysis of these samples. The resulting data are to be reduced, exchanged and evaluated, and the results are to be published yearly.

2. Develop methods to use pollutants for studies of material budgets, and as tracers for studies of physical and biological processes.

Dynamics of the ocean floor

1. Survey and prepare detailed charts of the morphology of the sea floor on a world-wide basis, with first emphasis on the continental margins.

2. Conduct reconnaissance geological and geophysical surveys of the continental margins.

3. Using air and ship borne magnetometers, complete the magnetic survey of the world ocean.

4. Carry out deep drilling at selected sites on the continental margins, mediterranean and marginal seas, and the deep ocean.

5. Conduct detailed investigations of the processes operating near ridge-rift crests.

6. Study the relationships between structures on the land and in the sea in selected trench-arc systems.

7. Use geophysical methods to elucidate the character of the crustal anomalies in certain deep ocean areas.

8. In mediterranean and marginal seas, conduct reconnaissance surveys related to both geological understanding and resource potential.

9. Install monitoring stations at selected river mouths, to determine the supply of sediments and dissolved materials from the land to the oceans.

10. Collect long cores and other geological samples from meridional profiles in the three oceans, to gain understanding of present and past world climates.

11. In several deep sea areas, survey the distribution and composition of manganese nodules.

In what geographical areas of the world's ocean will increased research efforts make the best contributions in solving these problems?

Even the most familiar areas of the world ocean are poorly known with respect to most of the problems discussed in this report. Thus, the systematic application of modern techniques of marine investigation to any part of the ocean is likely to yield useful results from both the scientific and economic points of view. Since international cooperative investigations are generally made up of coordinated national efforts, geographical priorities for the expanded program will usually be set by the existence of circumstances where a number of countries agree to work on a program of common interest.

While ocean research activities can be carried out on the high seas by suitably manned and equipped ships of any nation, in coastal waters there may be imposed some restrictions on research. Yet the distribution of the natural phenomena usually bears no relation to the limits established by man. Full understanding of these phenomena cannot be obtained if their investigation is unduly impeded.

From the point of view of the scientists involved in the present study, certain regions were suggested as being of particular interest. These are listed below.

World Ocean: Several projects involving the world ocean are proposed, including a global survey of primary production and herbivore biomass, the development of a more complete picture of the seasonal variation of surface circulation, the morphological charting of the sea floor, completion of the world ocean magnetic survey, and determination of the distribution of geochemical tracers on long meridional sections and an expanded global system of synoptic data on the surface of the ocean. Some of the experiments will also contribute to further development of global monitoring and forecasting systems. Around the coastal boundaries of the world ocean, a survey of potential sites for aquaculture is proposed as are the establishment of a network of stations for monitoring the input of pollutants and natural substances into the sea, and the geological and geophysical reconnaissance of the continental margins. Deep sediment drilling is proposed on numerous sites on the continental margins as well as in the deep ocean and the marginal seas.

Large ocean basins: Studies of the North Atlantic and North Pacific are suggested in order to understand better the large-scale and long-term variations of the physical environment and interactions with both the atmosphere and the biosphere. In the Arabian Sea, studies of the response of the ocean circulation to the monsoon are coupled with suggestions for exploratory surveys of the abundance of aminals of fishable size and for detailed ecosystem studies. Geological and geophysical studies are proposed for the mid-ocean ridges and rifts, for the investigation of anomalous deep ocean crustal areas and for the assay of manganese nodule potential. Exploratory surveys for living resources and accompanying environmental investigations are suggested for the Antarctic region.

Marginal and mediterranean seas: In addition to the geochemical sections across the entire ocean, it is suggested that such sections would be of value in adjoining seas such as the Philippine and Mediterranean Seas. Exploratory surveys of living resources and ecosystem studies are proposed in such regions as the Caribbean and the Gulfs of Thailand, Mexico and Alaska, as well as off the Indonesian and New Zealand shelves. Geological and geophysical studies of seas of this type are suggested both for locating unused resources and for gaining understanding of their origin and history. Studies are proposed that might in time lead to increased food production from such seas as the Adriatic, Red Sea or Gulf of California.

Coastal productive zones: Theoretical and observational programs for elucidating the process of coastal upwelling are proposed, both in the well-known system off California and in less-known regions such as the west coasts of South America and of Africa. Certain of these regions are suggested for detailed ecosystem studies. Apart from their physical and biological importance, these regions are the location of proposals in certain geological and geophysical investigations.

Deep-water circulation: The mechanism of deep water mass formation would be studied in the northernmost Atlantic, in the region of Mediterranean outflow, and in the Weddell Sea. The intermediate and deep circulation appears to be amenable to study off the Brazilian coast where investigation of the several layers of undercurrents, together with the surface circulation, is proposed.

<u>What kinds of supporting facilities, services and manpower will be needed to carry out these programs?</u>

An expanded program will place new demands on the already inadequate facilities, services and manpower available for investigation of the ocean and its resources. To carry out projects proposed in the present report will require additional ships for oceanographic, meteorological, and fishery research and for surveys and satellites with expanded observing capabilities. Some projects will need specialized craft such as submarines and drilling ships. Other kinds of necessary facilities for use at sea include instrumented buoys, a precise navigational system, improved equipment for making a variety of measurements and collections, and so forth. Ashore, there will be a need for additional experimental laboratories, sorting and analysis centers, standardization and test facilities and data centers.

An intensive effort will be required to improve methods of measuring various parameters so that data from cooperating units can be pooled. The system of data centers must be modernized and strengthened so that data can be rapidly exchanged, processed and analysed, and made available in useful forms. The development of synoptic oceanography and the need for exchanging some ocean data on a real-time basis may be met by integration with the meteorological data system. The expanded program will also necessitate improvement of methods and systems for the exchange and utilization of scientific information of all types.

Although a precise estimate of manpower requirements cannot be made at this early stage in the planning process, it is clear that a major increase will be necessary in technical and professional staff, especially in the developing countries. This increase cannot be achieved rapidly, and will require significant growth in the present effort in education and training.

<u>How can results of the above exploration and research programs best contribute to various peaceful uses of the ocean, its floor and its resources?</u>

The principal peaceful uses of the ocean, its floor, and its resources include the harvesting of living resources, the extraction of mineral resources, and the transport of people and freight across the surface. Man has also used the ocean as a receptacle for his waste products, thus leading to the problem of marine pollution. At the same time, he has increasingly turned to the sea shore for recreation. Information from the ocean surface layer is an important element in the forecasting of oceanic and atmospheric conditions.

Many of the programs of ocean exploration and research proposed by the working party are intended to contribute toward increasing the effectiveness of ocean utilization. For the most part, this contribution is indirect and large economic benefits should not be expected immediately. The philosophy underlying the various projects summarized above is that in the long-term, rational use of the ocean and its resources must be based on improved description and understanding resulting from scientific research. The proposed programs are intended to provide the scientific basis for assessment of potential resources, for the discovery of new resources, and for the rational management and conservation of these resources and of the marine environment. Further, these investigations are intended to facilitate the forecasting, not only of ocean and atmospheric conditions (over both land and sea) but also of the distribution and abundance of living resources, and of the ultimate distribution and fate of marine pollutants.

How can ocean exploration and research best contribute to the particular needs of the developing nations? How can increased ocean research activities by the developing countries contribute to their social and economic development?

The basic needs of all countries, regardless of their stage of development, include adequate supplies of food and of international exchange. The caloric requirements of a country's population are usually met through agriculture, a process that is sensitive to changes in weather and climate. In most coastal countries, accurate forecasting of weather over reasonable time periods could contribute significantly to increasing agricultural yields or to decreasing their cost. Ocean exploration and research in conjunction with appropriate meteorological investigations, should lead toward improved forecasts.

Animal protein requirements could be met in large part and at low cost by harvesting living resources from the ocean if the distribution problems could be solved. Ocean research can contribute to evaluation of the distribution, abundance and avilability of such resources in waters accessible to a country's fishermen, and can provide a basis for their rational utilization. The catch of living resources can be used either locally for food or as a source of foreign exchange.

Mineral resources from the continental shelf may also become a means of earning foreign exchange. Ocean research can assist in the location of such resources and in the assessment of their potential. The development of industrialization is associated with the construction or improvement of harbors and coastal installations, increased coastal shipping, great discharge of wastes into the coastal zone and increased recreational use of that zone. In each of these cases, suitable ocean research can contribute to selection of the most effective procedures for utilization, management or conservation and could permit forecasting of the possible environmental consequences of industrialization.

Given the eventual practical application of the results of ocean research to the social and economic development of countries, to what extent is it necessary for the country concerned to participate in the research?

There are, of course, certain kinds of data that can only be conveniently obtained by the coastal state. For example, after initial exploration of a region, a first requirement is to gain knowledge of the seasonal and year-to-year changes in ocean conditions, as they respond to meteorological changes and as they affect the marine flora and fauna. If a local fishery operates, records of the catch will show changes throughout the year. Monitoring of these various changes is only possible from a local base and is of immediate value to the adjacent country.

But there is a more fundamental reason for a developing country to participate actively in ocean research off its coasts. A nation requires full information on its natural resources. National policy regarding these resources is based on interpretation of the available information. Through participating in or conducting of ocean research, the country not only builds up the fund of knowledge on resource potential, but also is able to develop a group of scientists who, through their own work and their interactions with scientists elsewhere, can interpret this information and thus facilitate the rational evolution of national policy on ocean resources.

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LIST OF ABBREVIATIONS USED

ACMRR	Advisory Committee on Marine Resources Research, FAO
ECOSOC	Economic and Social Council of the United Nations
FAO	Food and Agriculture Organization of the United Nations
GARP	Global Atmospheric Research Programme
IBP	International Biological Programme
ICES	International Council for the Exploration of the Sea
ICSU	International Council of Scientific Unions
IGOSS	Integrated Global Ocean Station System
IOC	Intergovernmental Oceanographic Commission
SCOR	Scientific Committee on Oceanic Research
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WMO	World Meteorological Organization
WWW	World Weather Watch, WMO