Intergovernmental Oceanographic Commission

Workshop Report No. 37

IOC/Unesco Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs

Colombo, 8-13 July 1985

Unesco

IOC Workshop Reports

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No.	Title	Publishing Body	Languages
1	CCOP-IOC, 1974, Metallogenesis, Hydrocarbons and Tectonic Patterns in Eastern Asia (Report of the IDOE Workshop on); Bangkok, Thailand 24-29 September 1973 UNDP (CCOP), 138 pp.	Office of the Project Manager UNDP/CCOP c/o ESCAP Sala Santitham Bangkok 2, Thailand	English
2	CICAR Ichthyoplankton Workshop, Mexico City, 16-27 July 1974 (Unesco Technical Paper in Marine Sciences, No. 20).	Division of Marine Sciences, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock) Spanish (out of stock)
3	Report of the IOC/GFCM/ICSEM International Workshop on Marine Pollution in the Mediterranean, Monte Carlo, 9-14 September 1974.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish (out of stock)
4	Report of the Workshop on the Phenomenon known as "El Niño", Guayaquil, Ecuador, 4-12 December 1974.	FAO Via delle Terme di Caracalla 00100 Rome, Italy	English (out of stock) Spanish (out of stock)
5	IDOE International Workshop on Marine Geology and Geophysics of the Caribbean Region and its Resources, Kingston, Jamaica, 17-22 February 1975.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock) Spanish
6	Report of the CCOP/SOPAC-IOC IDOE International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific, Suva, Fiji, 1-6 September 1975.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
7	Report of the Scientific Workshop to Initiate Planning for a Co-operative Investigation in the North and Central Western Indian Ocean, organized within the IDOE under the sponsorship of IOC/FAO (IOFC)/Unesco/EAC, Nairobi, Kenya, 25 March-2 April 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
8	Joint IOC/FAO (IPFC)/UNEP International Workshop on Marine Pollution in East Asian Waters, Penang, 7-13 April 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock)
9	IOC/CMG/SCOR Second International Workshop on Marine Geoscience, Mauritius, 9-13 August 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
10	IOC/WMO Second Workshop on Marine Pollution (Petroleum) Monitoring, Monaco, 14-18 June 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish (out of stock) Russian
11	Report of the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions, Port of Spain Trinidad, 13-17 December 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish (out of stock)
11 Suppl.	Collected contributions of invited lecturers and authors to the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions, Port of Spain, Trinidad, 13-17 December 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
12	Report of the IOCARIBE Interdisciplinary Workshop on Scientific Programmes in Support of Fisheries Projects, Fort-de-France, Martinique 28 November-2 December 1977.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish
13	Report of the IOCARIBE Workshop on Environmental Geology of the Caribbean Coastal Area, Port of Spain, Trinidad, 16-18 January 1978.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
14	IOC/FAO/WHO/UNEP International Workshop on Marine Pollution in the Gulf of Guinea and Adjacent Areas, Abidjan, Ivory Coast, 2-9 May 1978.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French
15	CPPS/FAO/IOC/UNEP International Workshop on Marine Pollution in the South-East Pacific, Santiago de Chile, 6-10 November 1978.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock)
16	Workshop on the Western Pacific, Tokyo, 19-20 February 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Russian
17	Joint IOC/WMO Workshop on Oceanographic Products and the IGOSS Data Processing and Services System (IDPSS), Moscow, 9-11 April 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
17 Suppl.	Papers submitted to the Joint IOC/WMO Seminar on Oceanographic Products and the IGOSS Data Processing and Services System, Moscow, 2-6 April 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
18	IOC/Unesco Workshop on Syllabus for Training Marine Technicians, Miami, 22-26 May 1978 (Unesco reports in marine sciences, No. 4)	Division of Marine Sciences, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
19	IOC Workshop on Marine Science Syllabus for Secondary Schools, Llantwit Major, Wales, U.K., 5-9 June 1978 (Unesco reports in marine sciences, No. 5).	Division of Marine Sciences, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian Arabic
20	Second CCOP-IOC Workshop on IDOE Studies of East Asia Tectonics and Resources, Bandung, Indonesia, 17-21 October 1978.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
21	Second IDOE Symposium on Turbulence in the Ocean, Liège, Belgium, 7-18 May 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
22	Third IOC/WMO Workshop on Marine Pollution Monitoring, New Delhi, 11-15 February 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
23	WESTPAC Workshop on the Marine Geology and Geophysics of the North-West Pacific, Tokyo, 27-31 March 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Russian
24	WESTPAC Workshop on Coastal Transport of Pollutants, Tokyo, 27-31 March 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock)
25	Workshop on the Intercalibration of Sampling Procedures of the IOC/WMO UNEP Pilot Project on Monitoring Background Levels of Selected Pollutants in Open-Ocean Waters, Bermuda, 11-26 January 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (superseded by IOC Technical Series No. 22)
26	IOC Workshop on Coastal Area Management in the Caribbean Region, Mexico City, 24 September-5 October 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
27	CCOP/SOPAC-IOC Second International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific, Nouméa, New Caledonia, 9-15 October 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
28	FAO/IOC Workshop on the effects of environmental variation on the survival of larval pelagic fishes Lima, 20 April-5 May 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
29	WESTPAC Workshop on Marine biological methodology Tokyo, 9-14 February 1981.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
30	International Workshop on Marine Pollution in the South-West Atlantic Montevideo, 10-14 November 1980.	IOC, Unesco Place de Fontenoy, 75700 Paris, France	English (out of stock) Spanish
31	Third International Workshop on Marine Geoscience Heidelberg, 19-24 July 1982	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish
32	UNU/IOC/Unesco Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the context of the New Ocean Regime Paris, 27 September - 1 October 1982	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish

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Unesco

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1. OPENING

The Secretary of IOC, Dr Mario Ruivo, called the Session to order at 0800 on 8 July 1985. In keeping with local custom, he invited the Sri Lankan Minister of Fisheries, Mr. Festus Perera, to light the flower-bedecked oil lamp symbolizing the hope that the deliberations to follow will be likewise enlightened. The Minister was followed by the Secretary himself and the other personalities on the podium: the Representative of Unesco (Division of Marine Sciences), Dr Selim Morcos, and the Chairman of the Sri Lankan National Aquatic Resources Agency (NARA), Dr Hiran Jayawardene. 1

The Minister then welcomed the particpants to Sri Lanka. He stressed the opportunity the Workshop provided to take a step forward in regional co-operation at a time when, with the signing of the UN Convention on the Law of the Sea by a large majority of UN Member States, the countries of the region were seeking by all available means to press forward their socio-economic development. He recalled Sri Lanka's longstanding interest in promoting collaboration with its neighbours in the development of the marine resources, living and non-living, available to it in the Exclusive Economic Zone and beyond. It was, he said, as part of this trend that Sri Lanka had established its National Aquatic Resources Agency (NARA) under the Chairmanship of Dr. Hiran Jayewardene. Moreover, Sri Lanka had joined a number of other countries, from the Indian Ocean region and elsewhere, in moving a Resolution, which was adopted by the UN Conference on the Law of the Sea, aimed at reducing the gap between the developed and developing countries in respect of marine science and technology. If this is not achieved, many of the common goals of the countries concerned could not be achieved. He emphasized the important contribution that this scientific workshop could make to the First Conference on Economic, Scientific and Technical Co-operation in the Indian Ocean in the Context of the New Ocean Regime, to be held in Colombo from 15 to 20 July 1985, the following week. The Minister wished the participants in the Workshop every success in their endeavours. 2

The Secretary of the IOC responded. He expressed the regret of the Chairman of IOC, Prof. Inocencio Ronquillo, at not being able to attend. However, it was a great pleasure for the IOC and Unesco, as co-sponsors of the Workshop, to be in Colombo in this 25th Anniversary year of the IOC. He recalled that the IOC is an autonomous body within Unesco acting also as a joint specialized mechanism of several UN organizations: UN, FAO, WMO, IMO, as well as Unesco. It also co-operates closely with other UN organizations, notably UNEP. 3

During the International Indian Ocean Expedition (1959-1965), many countries from outside the region co-operated with those within it to advance knowledge of this major ocean. The expedition laid a basis for future regional co-operation. 4

However, one of the major objectives of the IOC is to facilitate such international dialogue and thus contribute to the evolution of the new ocean regime through, inter alia, activities such as those undertaken in the framework of the Training, Education and Mutual Assistance (TEMA) programme of the Commission 5 aimed at increasing national and regional self-reliance to improve significantly the predictability of natural events (monsoons, drought, floods, storm surges, etc.) and fish-stock abundance, much more detailed knowledge, of the state of the Indian Ocean, over extended periods, is needed. Such scientific knowledge is an instrument of economic development and a means to greater welfare, but, to acquire it, calls for enhanced international and regional co-operation.

6 The Secretary stressed the important role played by Sri Lanka in the Third UN Conference on the Law of the Sea, and recalled the efforts of IOC to respond to the needs of developing countries in respect of the enhancement of their marine scientific infrastructures, by mobilizing extra-budgetary funds to finance special regional or subregional projects under the Unesco-IOC Comprehensive Plan for a Major Assistance Programme to Enhance the Marine Science Capabilities of Developing Countries. In this connection, he mentioned the recently approved UNDP project on the strengthening of the National Aquatic Resources Agency (NARA), for which Unesco and IOC are the executing agencies.

7 The new ocean regime calls for the adaptation of national and international institutions and for an integrated approach to the rational use and management of marine resources. This was one of the reasons why India, Bangladesh, Pakistan and Sri Lanka put forward to the IOC Assembly, at its Twelfth Session, a Draft Resolution to establish the IOC Programme Group for the Central Indian Ocean. This was adopted by the Assembly as Resolution XII-14 which also called for the present Workshop to develop a programme proposal for consideration by the Programme Group aimed at providing a sound scientific basis for the rational exploration, exploitation and management of the resources of the central Indian Ocean.

8 The Secretary warmly thanked the Government of Sri Lanka, through the Minister of Fisheries, for its generous help in organizing the present Workshop.

9 The Chairman of the National Aquatic Resources Agency (NARA), Dr Hiran Jayawardene, expressed his satisfaction with the hosting of the Workshop in Sri Lanka and for the support that had been received from the UNDP project for the development of NARA and the technical assistance received in this regard from IOC and Unesco. He stressed the importance of the present Workshop to the development of regional co-operation in marine science and the related technology. He wished the participants success in their deliberations.

10 The Representative of Unesco, Dr. Selim Morcos, of the Division of Marine Sciences, reminded the participants that the present Workshop was the culmination of many national efforts to study the Indian Ocean during the past fifty years. He reviewed Unesco's contribution to training and research in the region over the last twewnty-five years, in the form of shipboard fellowships during the International Indian Ocean Expedition (IIOE), individual grants for study outside the region, specialized training courses and the establishment of the sorting centre that became known as the Indian Ocean Biological Centre (IOBC) in Cochin, India. From

these modest beginnings, the Division has developed its work to include major operational projects in several countries, such as the construction of marine science centres, research vessels and upgrading of related national infrastructure. Nine national and two regional projects are currently being executed. The Unesco Regional Project on Research and Training Leading to the Improved Management of Coastal Marine Systems (COMAR) covers such activities as assessment of important coastal ecosystems (mangroves, coral reefs, sea-grass beds). Together with the IOC, the Division of Sciences has co-sponsored the Mabahiss-John Murray International Symposium on Marine Science of the North-west Indian Ocean, held in Alexandria University in September 1983, to mark the fiftieth anniversary of the John Murray Expedition to the Indian Ocean aboard the Egyptian research vessel MABAHISS in 1933-34. A Round-table Discussion convened by IOC and Unesco at that Symposium laid a firm basis for the present Workshop.

The Representative of Unesco wished the participants every success in their deliberations and assured them of Unesco's support for the programme they would recommend. 11

2. ADMINISTRATIVE ARRANGEMENTS

2.1 DESIGNATION OF THE CHAIRMAN, VICE-CHAIRMAN AND RAPPORTEUR FOR THE WORKSHOP

Following consultations with participants, including scientists from the host country, the Secretary proposed Prof. Sena de Silva, of the University of Ruhuna, Sri Lanka, as Chairman. He also proposed Dr Salahuldin Quraishi, Director of the National Institute of Oceanography, Pakistan, and Dr. Boonlert Phasuk, Director of the Phuket Laboratory, Thailand, as the Vice-Chairmen of the Workshop. The Secretary then proposed Prof. Ahmed Refai Bayoumi, Director of the Institute of Oceanography and Fisheries, Egypt, as Rapporteur for the Workshop. 12

These proposals were approved by the participants by acclamation. 13

2.2 CONSIDERATION OF THE AGENDA

The Chairman invited the participants to comment on the Agenda. 14

It was suggested that discussion would be facilitated if Agenda Item 4.1 (Ocean Observing and Monitoring Systems) were taken immediately after Items 3.1 (Ocean Dynamics and Coastal Processes) and 3.2 (Ocean Processes and Climate) since it was closely related to these scientific activities. This proposal was accepted and the Agenda so revised is given in Annex I hereto. 15

2.3 CONDUCT OF THE WORKSHOP, TIMETABLE AND DOCUMENTATION

16 The Secretary of IOC briefly reminded the particpants of the nature and purpose of the Workshop: to produce specific proposals for feasible, scientific research projects and related ocean services, building on present work and local structures, as appropriate, and mobilizing the support of Member State Governments.

17 The Technical Secretary for the Workshop, Mr Ray C. Griffiths, informed the participants of the general intention to work in Plenary as much as possible, but to form <u>ad hoc</u> Sessional Drafting Groups to prepare project proposals on selected topics.

18 He outlined the Provisional Timetable (Document IOC/WC10/1 Add. prov.) and briefly reviewed the documentation for the Workshop (Document IOC/WC10/4).

19 The Workshop designated discussion leaders for certain Agenda Items, who also acted as Convenors of relevant Sessional Drafting Groups, as follows:

3.1	Ocean Dynamics and Coastal Processes	Dr S. Quraishi
3.2	Ocean Processes and Climate	Dr S. Quraishi
3.4	Ocean Science and Living Resources	Dr J. Stirn
3.5	Ocean Science and Non-Living Resources	Dr B. ul-Haq
3.6	Marine Pollution Research and Monitoring	Dr A. Jothy

20 Scientific lectures were given by some of the participants as background to the discussion of certain items. Abstracts of the presentations are given in Annex II. The full texts will be published in a separate Supplement to this Report. As far as possible, the International System of Units is used in this Report (see Unesco Technical Papers in Marine Science, No 45).

21 The List of Participants is given in Annex III and a List Acronyms is given en Annex IV.

3. <u>MARINE SCIENTIFIC KNOWLEDGE OF THE REGION AND FUTURE CO-OPERATION</u>

22 It was agreed that Agenda Item 3.1 (Ocean Dynamics and Coastal Processes) and 3.2 (Ocean Processes and Climate) should be taken together because they dealt with closely related aspects of the ocean. It was also agreed that project proposals for co-operative investigation of the central Indian Ocean and adjacent seas and gulfs should be preceded by a brief rationale and by a brief review of the present state of knowledge.

23 Considerable advantages will accrue to the Member States of the Indian Ocean region (or of any other ocean region) if they have a sufficiently detailed and extensive

knowledge of the physical, chemical, biological and geological nature of that ocean and the variability thereof. These advantages are, principally:

(i) provision of near-real-time knowledge of the state of the ocean for: maritime shipping (merchant ships, naval vessels, fishing vessels) to facilitate improved route selection (thereby reducing transit time or fuel consumption) and air/sea rescue operations; off-shore drilling and mining; and operation of off-shore observation platforms;

(ii) more precise predictions of the magnitude, frequency and impact zones of storm surges, cyclones and typhoons (so as to reduce risk to human life and property and to improve siting of coastal enterprises such as aquaculture - see also (vii) below);

(iii) more accurate regional weather forecasting and climate prediction (thus improving agricultural planning, crop protection against bad weather or pests, water supply and irrigation patterns and systems);

(iv) knowledge of the occurrence of upwelling, its extent, strength and location, as an indicator of possible fish abundance (and thus to improve the efficiency of fishery operations) or of the abundance of other living resources;

(v) better knowledge of the spatial and temporal distribution of commercially valuable fish resources (to allow more efficient fishery operations and the rational management of fish stocks);

(vi) increased predictability of potential risk to coastal areas from major pollution accidents whether the pollutants are discharged from the land into the sea or come from shipping operations or accidents;

(vii) knowledge of long-term trends in mean sea-level (to allow long-range planning of coastal land use, notably harbour construction, tourist-area development, location of nuclear power plants and other major industrial developments requiring massive amounts of cooling water, and possibly waste discharges).

3.1 and 3.2 OCEAN DYNAMICS AND COASTAL PROCESSES; OCEAN PROCESSES AND CLIMATE

The northern Indian Ocean, including the Bay of Bengal, 24
the Arabian Sea and the adjacent gulfs, is unique in respect of its physical oceanography and meteorology because of the monsoons.

Nowhere else does the ocean undergo such regular, widespread and large-scale seasonal changes in wind forcing and consequent changes in the characteristics of the ocean, especially the circulation. The uniqueness of the northern Indian Ocean and the monsoons led to several international expeditions, such as IIOE, ISMEX, MONEX, etc., which provided basic data on the oceanography and meteorology of the area. In spite of all these expeditions, our knowledge of the area is still quite meagre.

25 The Workshop briefly reviewed the present state of knowledge of the Indian Ocean in the two aforementioned fields, under several headings.

(i) Circulation and Physical Processes of the Arabian Sea and their Relationship to the South - West Monsoon and Productivity

26 The dynamics of the Arabian Sea have a direct impact on the economic development of the countries in the region. Seasonal changes in the Arabian Sea and reversal of the monsoon and its severity have a direct bearing on crops, irrigation systems, flooding of rivers and even on the breeding of marine organisms in the coastal region.

27 Monsoon Intensity and Geopotential Differences: The atmospheric forcing of the ocean during the south-west monsoon has been noted from the wind stress during summer months, when positive stress with strong gradients extends up to 70°E, almost covering the entire northern Arabian Sea. The area covered by the wind stress extends from the Somali coast up to the coasts of Pakistan and India, over 4,000 km. In view of the pronounced seasonal cycle in the atmospheric and monsoon oceanic circulation in the Indian Ocean, genesis of which starts in the transition month of April on the Somali coast, there is a possibility of forceasting the south-west monsoon intensity if the events are well recorded right from the African coast to the coast of the sub-continent, through the measurement of parameters such as geopotential, intensity of upwelling, temperature and thickness of the mixed layer, etc. There appears to be a correlation in the variation of surface geopotential differences at 1°N to 1°S off the coast and the intensity of the monsoon in Pakistan. The intensity of the rainfall during monsoon is also reflected in the high discharge of the Indus River which is usually in the month of August. The correlation between the geopotential differences off the Somali coast and the Indus discharge near the sea is positive. This correlation has a lag of about two months which can be used for prediction of monsoon intensity two months in advance. The physical processes connected with this forecasting mechanism are that, in the month of April, the South Equatorial Current at the African coast converges with the southward Somali Current and a loop-like southern feature is formed which moves northward. Thus, the early indication of the intensification of geopotential differences across the equator appears to have some relationship with the development of monsoon intensity.

Monsoon Intensity and Southern Oscillation: Other physical processes extending over larger oceanic areas, generally known as Southern Oscillations, also appear to have some correlation with the south-west monsoon variability. These oscillations are in fact a large-scale exchange of atmospheric mass between the eastern and western hemispheres. This may be visualized as a see-saw of high pressure in the South Pacific and low pressure in the Indian Ocean. It has a cycle of two to six years. The El Nino phenomenon has been found to be related to the Southern Oscillations. A long time-series of data from 1866 to 1977 (112 years) on monsoon intensity, classified as wet monsoon (strong) and dry monsoon (weak), were found to correlate with El Nino. Thus, there is a possibility of correlation between monsoon intensity and the Southern Oscillations. The investigation of physical causes and relationship between the oscillation and monsoon intensity will provide a good forecasting tool. 28

Monsoon Intensity and Thermal Structure: Monsoon intensity and the thermal structure of the Arabian Sea also appear to have a reasonable correlation. Sea-surface temperature and temperature at depth are affected by: the upwelling along the Somali and Arabian coasts and the circulation of upwelled water; outflow and mixing of Red Sea water at about 750-m depth, and the Gulf (1) water at about 250-m depth; cooling of the eastern Arabian Sea, which may be due to evaporation and mixing with deeper cool water, resulting in a deepening of the mixed layer. On the basis of the available scanty data, the depth of the isotherm in May appears to have some correlation with the August discharge of the Indus River. The depth of the isotherm, which is considered to be almost in the middle of the permanent thermocline, sinks forming deeper mixed layers. The high floods in the Indus River in 1967, 1973, 1976, 1978 and 1983 are reasonably well correlated with deeper depths of the isotherm; i.e., 180-200 m. Thus, there is a reasonably good correlation between temperature structure, particularly the depth of the thermocline, and the intensity of monsoon rainfall. 29

Monsoon Intensity and Eddy Circulation: The circulation of the Arabian Sea has also been observed, from satellite imagery, using a high-resolution infra-red radiometer, to contain warm- and cold-core eddies. The eddy circulations appear to intensify 30

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(1) The term Gulf (unless another specific gulf, such as the Gulf of Aden is understood from the context) means the semi-enclosed sea covered by the Kuwait Action Plan (of UNEP) and known variously as the Persian Gulf or the Arabian Gulf.

and, in some areas, persist in the south-west monsoon (May-September). These months are dominated by upwelling along the Arabian Sea coast, and the cold-water plume and wedge extend eastward. Comparatively weak upwelling also appears along the Pakistan coast, west of Karachi. In the middle of these two upwelled cold-water areas, an anticyclonic eddy is found with a warm core. Records generally show that this eddy circulation is repeated in the south-west monsoon. The warm-core eddies appear to transfer energy from the ocean to the atmosphere. Consequently, the rainfall of the sub-continent is affected. The thermal field of the warm-core eddy of June 1983 has been investigated. The normal surface temperature in June is 29°C, based on Wyrtki's (1971) bimonthly charts, when the mixed-layer depth is about 20-40 m. The depth of the 20°-C isotherm, which is in the middle of the permanent thermocline, ranges between depths of 120 and 160 m year round. These normal seasonal conditions are very much disturbed by the eddy circulation. Cool water, <26.0°C prevailed near the coast, and warm water, >29.0°C is trapped in the centre of the eddy. The trapping of warm water is reflected by the horizontal contouring of isotherms at 50-m and 100-m depths and less prominently at 200-m and 500-m depths. The 20°-C isotherm lowers to a depth of about 230 m which is associated with the eddy circulation. Thus, the information about the thermal structure in the eddy fields can also be a useful parameter for prediction of monsoon intensity.

31 <u>Eddy Circulation and Productivity</u>: In the warm-core eddy circulation of 1983, high values of phosphate and nitrate have been observed at the core. Mixing of the nutrients from the adjoining cool upwelled water, particularly from greater depths (150-300 m) is apparent. High phosphate concentrations (2.23 mole/l have been observed at the surface. In the Arabian Sea, dissolved oxygen concentrations generally decline rapidly with depth, particularly north of 20°N; the dissolved-oxygen content of the water in the thermocline decreases at temperatures of 26° - 27°C signifying that the oxygen demand exceeds the supply at 100 m. In the eddy fields, oxygen values of 3 ml/l at 100 m indicate that water trapped in the eddy field is well oxygenated, and oxygen concentrations were even as high as 3.5 ml/l, possibly because of the sinking of surface water, as indicated by the salinity distribution. The whole eddy field is rich in nutrients and dissolved oxygen, which would obviously be expected to increase the local biological productivity. Preliminary observations have indicated that the zooplankton is indeed rich, and standing crops (measured by displacement volume) of 0.29-0.72 ml/m^3 have been observed. More detailed studies are required to correlate the intensity of eddy with productivity.

32 <u>Conclusion</u>: It is possible to predict monsoon intensity from a few weeks to months, and even several years, ahead based on various physical oceanographic parameters and processes resulting from ocean and atmosphere interaction. However, detailed and systematic studies are required to understand the scientific phenomena and refine the forecast.

(ii) Storm Surges in the Northern Indian Ocean, including the Bay of Bengal and the Arabian Sea

There are two large marginal seas extending northward from 33
the Indian Ocean: the Bay of Bengal and the Arabian Sea. Coastal floods associated with storm surges - the changes in water level generated by storms passing over the sea - constitute the world's foremost natural hazard, surpassing even earthquakes for loss of life and property damage. Nowhere are these losses more serious than in the Bay of Bengal. These surges are caused by tropical cyclones which develop in the south-eastern part of the Bay or in the Andaman Sea at certain times of the year. The cyclones move along tracks that frequently cross the continental shelves bordering the Bay. A storm surge is generated partly by the resulting variations in atmospheric pressure, but the main contribution is produced by the winds, often of exceptional strength, acting over shallow water.

Storm surges are less frequent in Sri-Lanka than in 34
Bangladesh, India and Burma. There is no record of a major surge on the Bay of Bengal coast of Thailand. Storm surges are atmospherically forced oscillations of the water level in a coastal or inland water body in the period range of a few minutes to a few days. By this definition, storm surges are quite distinct from wind waves and swell which have periods from a few to several seconds. Storm surges belong to the same class of waves as tides and tsunamis; that is, long gravity waves. However, tides and tsunamis occur on the oceanic scale, whereas storm surges are essentially a shallow-water phenomenon.

The Bay of Bengal is a breeding ground for tropical 35
cyclones, the yearly average from 1890 to 1969 being 13. Tropical cyclones capable of generating surges usually occur during the pre-monsoon months (April to May) or the post-monsoon months (September to December), but rarely during the monsoon season. In Burma, storms occur mainly during the pre-monsoon months and affect the Arakan coast.

In the northern reaches of the Bay of Bengal and in the 36
Andaman Sea, the tidal range is comparable to the probable surge amplitudes. The relative timing of high tide and peak surge then becomes very important. The apparent importance of the non-linear effects suggests that dynamical tide-surge interaction must also play a part in the Bay of Bengal. The tide range decreases to the south, so that along much of the east coast of India the tides are small.

The eastern part of the Arabian Sea is an area of tropical 37
cyclone genesis. Most of the tropical cyclones in the Arabian Sea are locally generated. Occasionally, tropical cyclones from the Bay of Bengal traverse the peninsular part of India and become re-intensified over the Arabian Sea. Some cyclones recurve and make a landfall on the west coast of India or on the coast of Pakistan, whereas others travel west-northwestward and strike the south coast of the Arabian peninsula.

38 The frequency of occurrence of storms and storm surges in the Arabian Sea is much less than in the Bay of Bengal. However, the frequency appears to have increased in the last few years. On the Arabian Sea coastlines, the combined effects of storm surges and wind waves have generated water levels in excess of 5 m. If we take into account the high tidal range in the Arabian Sea (8 m at Bombay and 11 m at Cambay), the total water level due to the combined action of storm surges, tides and wind waves could reach 10 to 12 m under extreme conditions.

(iii) Physical Oceanographic Characteristics of the Gulf and the Gulf of Oman

39 The Gulf is a semi-enclosed shallow sea measuring 1000 km in length and varying in width from a maximum of 340 km to a minimum of 60 km in the Strait of Hormuz. It has an area of 226 000 square kilometres, and its average depth is about 35 m. The important topographic features are the deep water near the Iranian coast and shallow areas in the southern parts off the coasts of Saudi Arabia, Qatar and the United Arab Emirates. The oceanographic conditions in the Gulf vary drastically from summer to winter. High evaporation, low rainfall and limited exchange with the Indian Ocean lead to salinity values in excess of 40 and which may rise to 50 in the shallow coastal areas. The Gulf undergoes wide and rapid temperature changes in response to daily and seasonal cycles of heating and cooling. As with salinities, the highest water temperatures are found in the shallow bays and lagoons where the annual temperatures can range from 15°C in winter to 40°C in summer. Even well offshore, temperatures can range from 18°C in winter to 36°C in summer. Water circulation in the Gulf is governed by three factors: water movements resulting from evaporation; tidal currents; and wind-driven currents.

40 Although internal processes within the Gulf create very strong gradients, the volume of the outflowing water (3 100 cubic kilometres per year) is sufficiently small that its influence on the overall salinity balance of the Arabian Sea is insignificant. Within the northern Indian Ocean, the Gulf waters are found on the 26.6 density excess (γ) surface, lying at a depth of between 200 and 300 m and characterized by a weak salinity maximum. Duing and Sohwill have examined the spread of Gulf water within the Indian Ocean in terms of a horizontal diffusion model; the salinity signal can be traced to about 12°N .

41 Hartmann *et al*. provided a volume-transport budget by considering

V_{in} = 3 365 km^3 per year; $V_{precipitation}$ = 34 km^3 per year

V_{out} = 3 130 km^3 per year; V_{river} = 37 km^3 per year

$V_{evaporation}$ = 326 km^3 per year

Then, from a volume of water within the Gulf of 7 800 cubic kilometres, a residence time of about 2.5 years can be estimated. Since the evaporation term is about 10 times the precipitation or river input, this is plainly the dominant control. The best estimate of evaporation comes from Privett who gives a mean annual evaporation of 144 cm per year, with a maximum in December and a minimum in May. 42

The Gulf is mainly affected by the extra-tropical weather systems, whereas the Gulf of Oman is at the northern edge of the tropical weather systems. Thus the Strait of Hormuz region forms the boundary between the extra-tropical weather systems generally travelling west-to-east and tropical weather systems travelling east-to-west. 43

One of the interesting weather phenomena in the Gulf region is the so-called "Shamal", which is a subsynoptic-scale wind phenomenon that occurs in this region with sufficient frequency and influence on the local weather that it is significant operationally. Shamal is an Arabic word meaning "north". It is used in the meteorological context to refer to seasonal northwesterly winds that occur during winter as well as summer in the Gulf region. 44

The usual relationship between wind speed and wave height that is true for deep water may not hold for the shallow Gulf whose maximum depth is only 73 m. According to Perrone, the shallowness of the Gulf, as well as its stratification, will make the wave heights much larger than those that may be inferred from the deep-water relationships. Observations made from oil rigs suggest that persistent gale-force winds blowing for up to 12 hours can generate wind waves with amplitudes up to 4 m. Sometimes, waves up to 5-m height may be generated in a few hours. 45

In the northern part of the Gulf, wind-wave amplitudes are usually smaller owing to limited fetch and to the fact that this area is affected by short-lived Shamals. According to Perrone, the following three factors combine to generate waves up to 5-m height in the southern part of the Gulf during Shamals of three to five days' duration: (a) the increase in the wind speed in the southern part of the Gulf; this contributes to locally generated seas; (b) the longer duration of gale-force winds over the whole Gulf; the northern part of the Gulf generates swell which travels into the southern part; (c) the lack of fetch limitation; the entire Gulf experiences at least gale-force winds, with the strongest winds in the southern part. It may take several days for the swell to decay following Shamal winds. 46

The tidal ranges are large throughout the Gulf, being over a metre everywhere and exceeding three metres at Shatt al-Arab. These large amplitudes cause strong tidal currents which commonly exceed 0.3 m/s at maximum ebb or flood. The tides generally flow westward and northwestward and ebb in the opposite directions. This gives the appearance of the tide progressing up the Iranian coast and down the Saudi Arabian side, with the range increasing from the middle of the Gulf in Kelvin-wave style. The dimensions of the Gulf are such that the oscillations in the tide are not too far from resonance. The four main harmonic constituents of the tidal regime in the Gulf are M_2, S_2, O_1 and K_1. 47

48 It has been known for a long time that evaporation exceeds precipitation in the Gulf, and so it would be expected that the more saline dense water would sink and pass out of the Strait of Hormuz, giving rise to a compensating surface flow of less dense water into the Gulf. The effect of the earth's rotation would be to deflect these flows to the right, giving a surface flow west and north-west along the Iranian coast, and a deep flow to the south-east and east along the coasts of Saudi Arabia and the United Arab Emirates (the deep flow would be further constrained by these latter coastlines, since it is in these regions that the shallow sea areas of high evaporation lie). The circulation pattern would undoubtedly be modified by forcing by wind and atmospheric pressure, but it has been generally supported by observations of ships at sea.

49 In view of the inter-relationship of oceanic processes between local and small-scale phenomena and large-scale oceanic processes coverning the whole of the Indian Ocean, it is imperative to identify large-scale oceanic processes so as to plan the research projects for the IOCINDIO region. The large-scale oceanic phenomena of the Indian Ocean relevant to present considerations are as follows

Northern Monsoon-driven Regime

(a) The reversing Somali Current and cross-equatorial western boundary current.
(b) The cooling of the Arabian Sea.
(c) The reversing current south of Sri Lanka.
(d) The semi-annual equatorial jet.
(e) The reversing sub-equatorial current and sub-tropical convergence.
(f) The water exchange between the Pacific and Indian Oceans.

The Subtropical Gyres and the Sub-Antarctic

(a) The Indian Ocean-Atlantic Ocean exchange (the fate of the Agulhas water).
(b) The interaction between the Agulhas and East Malagasy (Madagascar) gyres.
(c) The formation of mode water.
(d) The Leuwin Current.
(e) The circulation near Antarctica.
(f) The heat transport by eddies.
(g) The meridional deep current.

50 The Workshop recognized that new technology, such as satellite remote sensing, numerical simulation modelling, deep-sea submersibles and automatic instrumentation, offer the prospect of forecasting significant anomalies in the normal variability of oceanographic features in the Indian Ocean. Observations so far have indicated seasonal and climatic variability in the Indian Ocean atmospheric and oceanic circulation affecting the monsoonal regime through mixing of water masses from the Gulf and Red Sea with those of the Arabian Sea, changing pattern of winds and oceanic currents and thermal structure, formation of devastating waves, tides and surges in the marginal seas of the Arabian Sea and the Bay of Bengal.

The Workshop, having reviewed current knowledge of the central Indian Ocean and adjacent seas and gulfs recommended the implementation, under the aegis of the IOC Programme Group for the Central Indian Ocean, of three co-operative scientific research projects, which are described below (paragraph 52 et seq.). It stressed the importance of several related factors: (a) the recommendations of the Indian Ocean Climate Studies Panel of the Joint SCOR-IOC Committee on Climatic Changes and the Ocean (CCCO) regarding scientific programmes under TOGA and WOCE, which are briefly described later (paragraphs 97 and 98); (b) the fullest possible participation of the Member States of the region in related programmes and activities, notably TOGA and WOCE, bearing in mind the relevant national capabilities and facilities; and (c) appropriate co-ordination between the activities of the Programme Group and these other relevant activities. 51

PROJECT PROPOSALS

The three project proposals are on: Coastal Water Dynamics; Water Mass Movements; and Storm-surge Prediction for the Marginal Seas of the Northern Indian Ocean. These projects are expected to contribute to the establishment of a sound footing in oceanographic research in this region and will attempt to solve some of the crucial and immediate problems affecting human lives and national economies. 52

(i) COASTAL WATER DYNAMICS

Rationale

Physical oceanographic investigations pertaining to the offshore areas of the countries of the IOCINDIO region are not only important to the countries' national marine development programmes but are also complementary to other large-scale regional and international oceanographic programmes in the Indian Ocean, and even global oceanic and atmospheric research programmes. 53

These programmes are within the national capabilities of the countries of the region. Some countries have well developed oceanographic research capabilities and are equipped to participate in all aspects of oceanographic activities in their offshore areas; some countries are in the process of development, and some require incentive and assistance in the initiation of oceanographic research. 54

Circulation in the offshore areas of the central Indian Ocean countries, in the form of clockwise and anti-clockwise gyres during reversal of monsoons, outflow of Gulf and Red Sea water into the Indian Ocean from the west, flow through the Indonesian Archipelago from the east, eastward and westward flow between the Arabian Sea and the Bay of Bengal around Sri Lankan offshore areas, joins the countries of the region and creates a common reason to study the dynamics and composition of the sea. 55

56 Many living and non-living resources are near the coastal areas over which the coastal countries have rights and obligations in respect of their exploration, exploitation and conservation. Best results can be achieved knowing thoroughly the circulation in the offshore areas, types of water masses and their mixing and the exchange of energy between ocean and atmosphere.

57 Under the new ocean regime, as manifested in the UN Convention on the Law of the Sea, and the creation of Exclusive Economic Zones (EEZs), responsibilities have devolved on the coastal States for the protection, conservation and management of the resources of the EEZ, and this can be achieved through intensive scientific research, of which physical oceanographic research is an important component.

58 Studies of coastal-water dynamics have direct application to coastal processes such as erosion, siltation and pollution, and to environmental management and the study of coastal ecology.

59 During the IIOE, there were many gaps in the observational programmes, particularly in the near-shore areas of the region. Stress should be laid on filling these gaps so as to improve understanding of the overall dynamics and oceanic processes of the region.

Objectives

60 The general objective of this project is to increase understanding of the ocean and coastal processes that affect climate, navigation, exploration and exploitation, coastal-zone development and environmental management etc. The project should also:

- contribute, through related training activities, to increasing the number of coastal marine scientists and technicians in the region;
- provide appropriate data, in quality and quantity, to allow development of mathematical models by which to forecast coastal environmental conditions better;
- generally create the scientific basis required for effective management of coastal resources - living and non-living;
- provide a stronger basis for further regional co-operation in the field of oceanography.

Observational Requirements

61 Many countries of the region have oceanographic capabilities that may be applied to meeting the objectives of the project.

62 Existing and projected programmes already identified by each country should be supported, and participation in these programmes by the countries of the region should be co-ordinated by the IOC through IOCINDIO.

There is a big gap in the data and information on the coastal water dynamics of the region. Countries should be encouraged in the exchange of data amongst themselves and through World Data Centres. 63

There is a serious lack of data relevant to common problems of the countries of the region; examples are: variation in mean sea level (determined through a tide-gauge network); variation in the thermal field (determined through XBT observations); variation in currents (determined through current-meter observations); and atmospheric changes (determined through meteorological observations). 64

Countries that have capabilities for collecting information on off-shore dynamics (remote sensing through satellites, automatic sea-observing buoys, etc.) should be encouraged to exchange information with the countries of the region. 65

Several developed countries and renowned international marine scientific institutions are carrying out research on important scientific problems relating to the overall mechanism that not only affects the circulation in the offshore areas, but is also related to variation in the rainfall and productivity, which in turn are directly related to the agriculture and fisheries of the countries of the region. Participation of the regional countries in such international programmes and the supply of information and data etc. should be promoted and co-ordinated by IOC. 66

(ii) <u>WATER-MASS MOVEMENT</u>

<u>Rationale</u>

The outflow of the dense Red Sea water through the Straits of Bab el-Mandab, and of Gulf water through the Straits of Hormuz into the Arabian Sea, creates perturbation in the prevailing seasonal circulation resulting in a change in the physical characteristics of water masses of the Arabian Sea. 67

Very little is known about the mixing of these dense water masses with the Arabian Sea water masses or about their influence on the vertical thermal structure which is related to the variation in the monsoon intensity in the Arabian Sea. 68

Detailed investigations are required to trace the movement of these water masses in the Arabian Sea and in the northern Indian Ocean, and the redistribution of energy. 69

The chemical properties of water masses, particularly their content of nutrients and dissolved oxygen, and their CO_2-system parameters, are important in the identification of water masses and their circulation patterns; they are also important to the understanding of biological processes. Certain studies of the chemical oceanography of the central Indian Ocean should be promoted, as, for example: nutrient balances in the Red Sea and the Gulf and the exchange of nutrients with the Arabian Sea; the denitrification of the Arabian Sea and adjacent waters; the cause and significance of the oxygen minimum; etc . 70

71 The relation of these water masses and the productivity of the central Indian Ocean region requires to be assessed. The circulation of these water masses will create non-linearity in the numerical models for upwelling and for general oceanic circulation, which can be resolved through the knowledge of their spatial and temporal distribution in the Indian Ocean.

Objectives

72 The specific project objectives are:

- to map the movements of the main water masses of the region so as to clarify their role in the creation of weather, regional climate variability, productivity, biomass distribution, and environmental hazards etc;

- to increase open-sea oceanographic capabilities in the region;

- to generate appropriate data for the development and testing of circulation models of the Indian Ocean so as to improve predictability of major ocean phenomena.

Observational Requirements

73 Several countries of the region have the oceanographic capabilities required to achieve the objectives of this project.

74 The existing data so far collected and the information available in various institutions, World Data Centres, archives, etc. should be synthesized in a review document, under the co-ordination of the IOC.

75 The following regular observations are proposed: repeated hydrographic sections; tide-gauge observations on either side of the Straits of Bab el-Mandab to record sea-level changes and to check absolute current data; current metering at selected locations through moored current meters.

76 Outflow can also be monitored through remote sensing using high-resolution infra-red imagery, and the co-operation of countries having such facilities should be mustered.

77 Large quantities of thermal observations from XBT records should be arranged using ships-of-opportunity in the region.

(iii) STORM-SURGE PREDICTION FOR THE MARGINAL SEAS OF THE NORTHERN INDIAN OCEAN

Rationale

78 The two large marginal seas of the northern Indian Ocean are the Bay of Bengal and the Arabian Sea. The Arabian Sea joins, at its northern end, the Gulf of Oman and the Gulf. At its northwestern end, the Arabian Sea joins the Gulf of Aden and the Red Sea.

Storm surges are oscillations of the water level in a coastal or inland water body, with a period ranging from a few minutes to several hours. These are generated by the wind stress and atmospheric pressure gradients associated with travelling weather systems such as cyclones. 79

Coastal floods associated with storm surges constitute the world's foremost natural hazard, surpassing even earthquakes for loss of life and property damage. The Bay of Bengal alone accounts for about 60% of the deaths and destruction, with Bangladesh accounting for at least 40%. A recent surge in Bangladesh on 24 May 1985 killed several thousand people. 80

While immediate loss of life is often the most dramatic result of a major surge, other effects can also be very serious. The most devastating surge in this century was that which struck Bangladesh in November 1970. Human deaths caused by the surge were estimated to be about 275 000, but there was also enormous economic damage. Almost all the livestock in the surge-affected area was drowned, and most of the fishing fleet was destroyed. Damage due to storm surges in the Bay of Bengal during 1945-75 was estimated to be in excess of 7 billion US dollars. 81

The coasts of Burma, Bangladesh and the east coast of India have been subjected to frequent severe surges. The Andaman Sea is a breeding area for tropical storms and depressions, the yearly average being about 13. In the 110-year period 1876-1985, there were about 72 major and moderate surges in the Bay of Bengal and at least 800 000 people were killed. Although the frequency of surges on the Sri Lanka coast is somewhat less than in Bangladesh, India and Burma, surges do occur. A major surge in 1978 killed several hundrd people, and a moderate surge on 29 June 1985 killed 8 people and caused considerable destruction. 82

Although storm surges in the Arabian Sea are not as frequent and as destructive as those in the Bay of Bengal, they occur not infrequently. In the last ten years, there have been three major surges and some minor ones killing a few hundred people and causing great damage. Surges occur on the west coast of India, on the Pakistan coast and along the south-west coast of the Gulf. 83

In contrast to the Bay of Bengal, there has been very little modelling activity for surges and tides in the Arabian Sea and the other connecting marginal seas. Thus, for the Arabian Sea, not only a deep-ocean tide-gauge programme is needed (as for the Bay of Bengal) but also systematic development of mathematical models is required before reliable storm-surge predictions can be made. 84

The Arabian Sea modelling could be done at the NIO, Goa, and at at the NIO, Karachi. The modelling for the Gulf and the Red Sea could be done at the University for Petroleum and Minerals, in Dhaharan, Saudi Arabia, and at KISR, Kuwait. 85

The tide-gauge programme not only facilitates prediction, but is helpful for navigation, development of ocean resources, etc. It is estimated that the storm-surge and tide-gauge programmes for the marginal seas of the northern Indian Ocean will directly benefit about 28 nations. 86

Objectives

87 The objectives of this project are:

- to increase substantially regional capabilities to predict storm surges and their probable landfall so as to enhance storm-surge warning systems;
- to develop mathematical models of ocean dynamics in the region for prediction purposes;
- to contribute data on mean sea level to related studies.

Observational Requirements

88 For storm-surge prediction, it is not sufficient to predict the amplitude of the peak surge alone. It is necessary also to predict at what stage of the tide the peak surge will occur. For example, the November 1970 surge mentioned above was so destructive mainly because the peak surge occurred at the time of high tide. On the other hand, a comparable surge in October 1981 in the same area caused little damage because the peak surge occurred close to the time of low tide, and the combined water level due to the surge and the low tide was not significant.

89 There is considerable local expertise in India, Bangladesh and Burma on the mathematical modelling of storm surges. The existing mathematical models for Bay of Bengal storm surges do not include Sri Lanka. Hence models have to be developed separately for Sri Lanka, which experiences surges on its east as well as west coast.

90 To develop accurate storm-surge prediction models, there is not only the problem of the uncertainties in predicting the time and location of landfall of the cyclone and the associated wind field. It is also necessary to describe and model the tide entering the Bay from the Indian Ocean. To be able to do this, the tidal amplitude and phase have to be measured at several locations along the open boundary between the Bay of Bengal and the Indian Ocean. Ideally, 10 to 15 deep-ocean tide gauges should be placed on the ocean bottom in two to three rows across the Bay and left there for a duration of 12 to 18 months to register the tide. Such equipment is available at present in several countries, including the USA, UK and Canada.

TRAINING NEEDS

91 The training of scientists and technicians through international co-operation under the aegis of IOC's programme of Training, Education and Mutual Assistance in the Marine Sciences (TEMA) is necessay to fulfil the objectives of the three project proposals outlined above. It is desirable that the training be linked with specific

scientific activities and projects so that continuity may be maintained in the progress of the projects. The following areas of training should be given high priority: (i) remote sensing; (ii) modelling; (iii) data management; and (iv) oceanographic observation methods and maintenance of instruments and equipment.

RELATIONSHIP WITH THE WORLD CLIMATE RESEARCH PROGRAMME

The Workshop recognized the fact that some aspects of the three project proposals mentioned above would complement certain activities in the framework of the oceanographic component of the ICSU-WMO World Climate Research Programme. The objectives and the strategy of the WCRP are developed in the Scientific Plan for the WCRP (WCP Series No. 2, 1984). Most of the scientific planning of oceanographic experiments for the WCRP has been carried out by the SCOR-IOC Committee on Climatic Changes and the Ocean. IOC has also assumed responsibility, through its Programme Group on Ocean Processes and Climate, for co-ordinating the oceanographic component at the intergovernmental level. The First Session of the Programme Group took place in March 1985. The IOC will also co-sponsor the WCRP Planning Meeting to be convened in May 1986. The first WCRP implementation plan will be presented to governments at that meeting. 92

The goals of the WCRP have been formulated in terms of three streams each corresponding to different time scales. The first stream aims at establishing the physical basis for the prediction of weather anomalies on time scales of one to two months. The second stream aims at predicting the variations of the global climate over periods up to several years. The third stream aims at characterizing the variations of the atmospheric climate over periods of decades and assessing the potential response of climate to natural or man-made influences, such as the increase of the concentration of atmospheric carbon dioxide. 93

The distinction of the three different streams constitutes a step-by-step approach to the climate problem, activities of stream 1 contributing to the achievement of stream 2 objectives, and streams 1 and 2 contributing to achieving the objectives of stream 3. 94

Progress in meteorology and oceanography has now shown the necessity of addressing climatology on a global scale and through the study of the ocean and the atmosphere as a coupled system. As the scales of interest increase, the modifying influences of the entire ocean become increasingly important. A better understanding of the world-ocean processes and the consideration of the ocean and atmosphere as a coupled system become pre-requisites for significant progress in furthering knowledge of climate and in improving the ability to predict it. Oceanographers and meteorologists have to work together and knowledge of the ocean has to improve significantly. 95

The specific oceanographic activities that are planned to achieve the objectives of the WCRP and which require international co-ordination for their implementation are: 96

(i) Study of the Tropical Oceans and the Global Atmosphere (TOGA)

97 The TOGA study is focussed on the upper tropical ocean and overlying atmosphere in order to understand, and eventually predict, the evolution of tropical ocean perturbations and the global atmospheric response. The overall aims of TOGA encompass the objectives of the Monsoon Climate Programme (i.e., to determine the nature of the long-period fluctuations of the monsoon and their relationship to the planetary-scale circulation). Extensive measurements of the tropical oceans made concommitantly with observations of the global atmosphere in 1985-1995 will provide the basis for the development of a coupled prognostic model.

(ii) World Ocean Circulation Experiment (WOCE)

98 The objective of WOCE is to determine the main large-scale heat and water fluxes, their variability and the response of the ocean circulation to natural or man-made changes. It will address the determination of possible trends in the earth's climate over decades. The primary objective of WOCE is the development of a global circulation model. A five-year extensive observational period is to be synchronized with the flights of satellites equipped with sensors specifically designed to measure the global surface wind field and the absolute height of the ocean surface (1990-1995).

(iii) An Ocean Observing System Development Programme (OOSDP)

99 The objective of OOSDP is to establish a global network of the necessary oceanographic measurements to be monitored for climate prediction. The annual cycle of the Indian Ocean is dominated by the monsoon circulations; it is of crucial importance to the surrounding countries and provides the most outstanding examples of pronounced seasonal cycles. The interannual variability of the monsoons is now thought to be teleconnected with climatic events throughout the world. The understanding of such events will not be complete unless the system is studied as a whole. International co-operative studies in the Indian Ocean will be, therefore, major elements of the WCRP experiments. The report of the second meeting of the CCCO Indian Ocean Climate Studies Panel (New Delhi, 28-31 Jan 1985) outlines the relevant experiments in the area. A sea-level network and a suitable grid of routine measurements of temperature profiles are being organized. A joint IOC-WMO Meeting on the Implementation of IGOSS XBT Ship-of-Opportunity Programmes is to be convened in Seattle in September 1985. Arrangements to install the necessary tide-gauges are being made under the IOC Global Sea-level Observing System. The priority is, at present, to focus on these two sub-programmes for the TOGA experiment. In addition, many countries have declared their intention to undertake various oceanographic studies. The oceanic response to the monsoon encompasses the western boundary currents, the equatorial current system and the subsurface flow.

Several numerical models of these systems are being developed. However, the observational data in this ocean are still too scarce to test these models and even to design the optimum sampling strategy. Much has to be gained during the next decade from a large involvement of countries. Within five years, WOCE will emphasize studies of the deep circulation, heat transport, and interconnections of the Indian Ocean with the world ocean through the Antarctic Circumpolar Current. At that time, the set of observations will be adequate to take full advantage of the satellite sensors planned for the 1990s.

The Workshop recognized the relevance for the IOCINDIO region of the oceanographic programme being undertaken in the context of the WCRP, in particular the TOGA study, with a view to increasing the capability for the prediction of the monsoon. It also recognized that the regionwide collection of data and the development of circulation models are essential and complementary to the project proposals listed above in respect of ocean dynamics and coastal processes. The observational programme elements of interest include: 100

- repeated measurements of temperature, salinity and currents to describe the characteristics and the behaviour of the water masses;

- the establishment of a tide-gauge network to determine the large-scale Indian Ocean sea-level topography and its variability; and

- measurements of wind, moisture, sea-surface and air temperatures, to provide the main inputs for ocean-circulation models.

The Workshop recommended that the countries of the central Indian Ocean and adjacent seas and gulfs take an active part in the projects to be carried out within the oceanographic component of the WCRP the overall objectives of which encompass various regional interests, and that the IOC Programme Group for IOCINDIO assist with the implementation of the appropriate components of TOGA and WOCE. 101

It also recommended that the IOC Programme Groups for IOCINDIO and for IOCINCWIO co-operate in the study of ocean phenomena of common interest to both regions, not only in the context of the three projects proposed above, but also in the wider context of the oceanographic component of the WCRP. 102

3.3 OCEAN OBSERVING AND MONITORING SYSTEMS

Relative to the observational requirements identified in the scientific project proposals described in Sections 3.1 and 3.2, three major international ocean service activities are being developed under the aegis of IOC: 103

- a Global Sea-level Observing System;
- a ship-of-opportunity subsurface-thermal-structure programme (under the IOC-WMO Integrated Global Ocean Services System - IGOSS); and
- a drifting-buoy programme, jointly with WMO.

Global Sea-level Observing System

104 The IOC has reviewed the need for a global network of sea-level stations, and a project proposal was considered and accepted by the IOC Programme Group on Ocean Processes and Climate, at its First Session, and by the IOC Assembly at its Thirteenth Session, both in March 1985. Sea-level stations should be improved (if existing) or established to achieve the following objectives:

- to respond to national needs for practical and research applications (data should be submitted to the Permanent Service for Mean Sea-Level (PSMSL) for archiving and processing into data products for specific users, in the framework of the IOC's International Oceanographic Data Exchange System);

- to allow the monitoring of monthly sea-level anomalies (data should be transmitted to specialized centres; a monthly map of basin-scale sea-surface topography will be issued, as is already done in the Pacific);

- to facilitate the determination of long-term climatic changes (data should be submitted to PSMSL); and

- to facilitate the calibration of satellite altimetry (some chosen locations from which the data will be transmitted in real time).

105 The distribution of the existing (●) or proposed new stations (X) are shown in Figure 1. This is regarded as the minimum network required to achieve the stated objectives. However, this does not not preclude the possibility that additional, new stations be established in other localities of special maritime significance or interest, such as the Straits of Malacca or the entrance to the Gulf of Aden which has no such stations at present.

Ship-of-opportunity programme

106 It has been demonstrated that an XBT programme can be implemented reliably on selected ships of opportunity to monitor seasonal variability of the sub-surface temperature field and to detect large-scale anomalies. A regular XBT programme is being organized under the auspices of the IOC-WMO Working Committee for the Integrated Global Ocean Services System (IGOSS), in areas of key interest for TOGA and to determine first-order large-scale variability for WOCE. In addition, this programme will permit a better determination of the spatial and temporal scales of the variability in the Indian Ocean, a pre-requisite for further planning of process studies. The tracks of merchant ships' routes that it is proposed to utilize are indicate in Figure 2. The data will be collected in specialized centres through IGOSS and will be further exchanged within IODE.

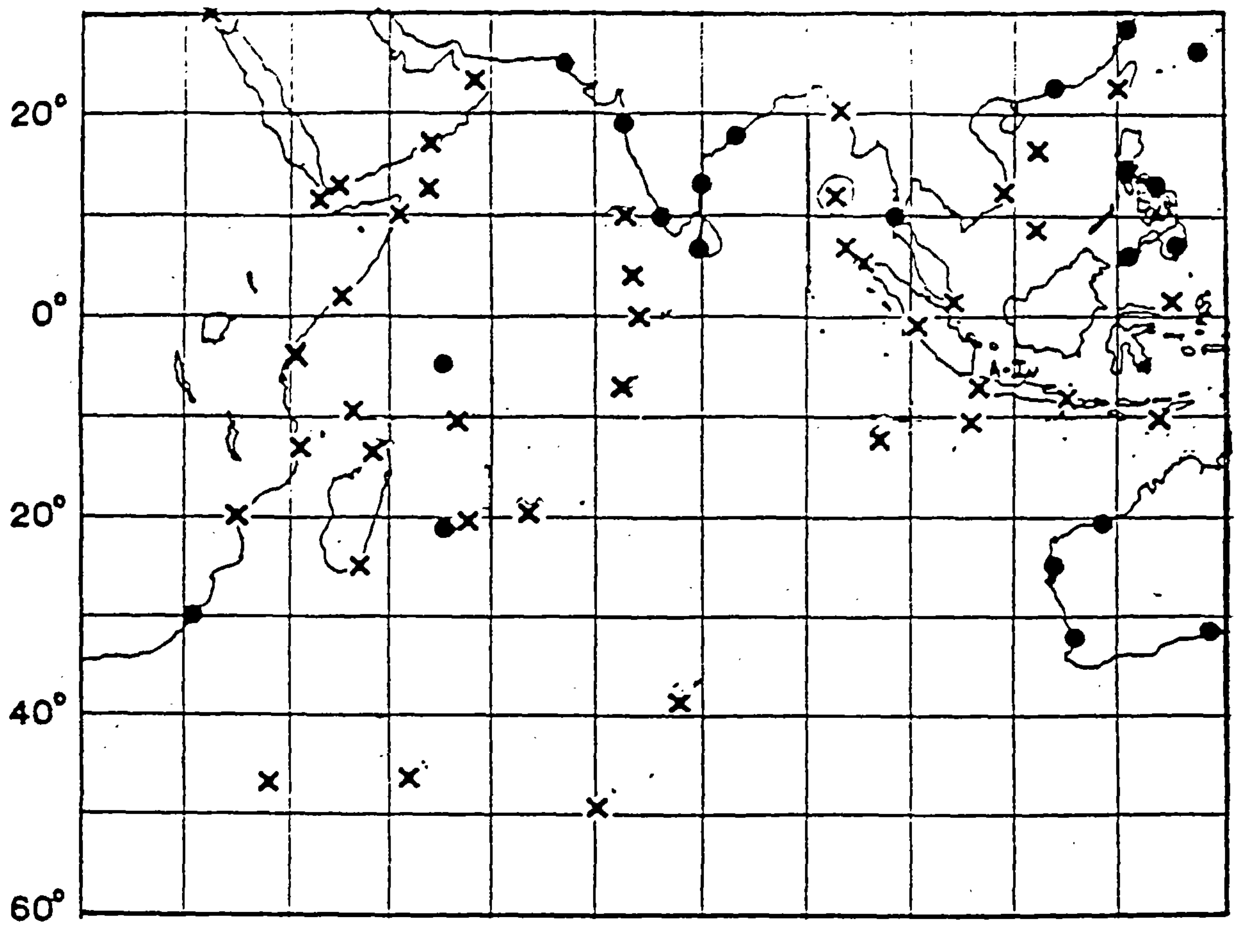

Figure 1. Proposed tide-gauge network
(● = existing stations; x = proposed new stations)

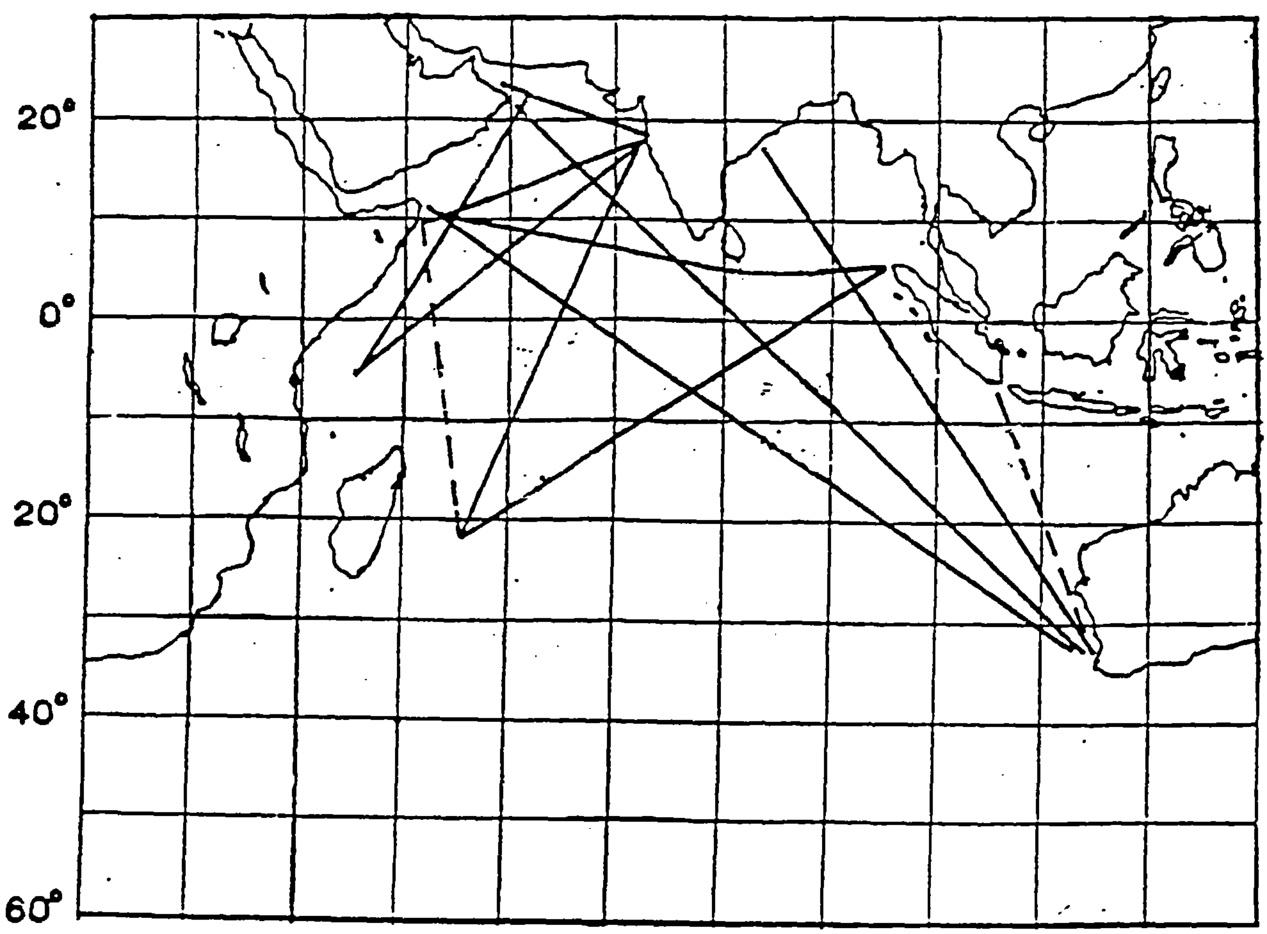

Figure 2. Proposed XBT tracks

Drifting buoys

107 These have proved to be an efficient and cost-effective observing system for the acquisition of meteorological and oceanographic measurements. During the Global Weather Experiment in 1977-1980, the number of Southern Ocean drifting buoys reached some 350 at the peak and contributed greatly to the success of the Experiment. With the progress of the World Weather Watch (WWW) and TOGA drifting-buoy programmes, the world ocean is again covered with an extensive network of operational drifting buoys which produce, through the ARGOS system, real-time sea-surface temperature (SST), air temperature and air-pressure data; on average, 900 reports from about 120 drifting buoys are transmitted every day on the WMO Global Telecommunication System (GTS). Of particular interest to the Indian Ocean are TOGA drifting buoys which are being deployed in the tropical belt by such countries as Australia and USA. It is hoped that TOGA buoys will soon be equipped with reliable devices for the measurement of sub-surface temperature which is of particular importance to operational and research programmes; e.g., IGOSS, WWW and WCRP. Since operational drifting-buoy data are distributed over the GTS, countries bordering the Indian Ocean have a direct access to these data through GTS centres or associated oceanographic centres. The IOC and WMO are presently considering the establishment of a consortium for the co-ordination of oceanographic/meteorological drifting-buoy activities.

108 The Workshop welcomed these initiatives to develop relevant observing and monitoring systems and recommended that the countries of the region co-operate as fully as possible in this development.

3.4 OCEAN SCIENCE AND LIVING RESOURCES

109 The Workshop briefly reviewed the state of knowledge of the living resources of the region. Several proposals for regional research projects or recommendations for action, including co-operation in on-going studies, were indentified.

PROJECT PROPOSALS

(i) DISTRIBUTION OF OCEANIC PELAGIC RESOURCES (WITH PARTICULAR REFERENCE TO TUNA) IN RELATION TO THE ENVIRONMENT IN THE INDIAN OCEAN REGION.

Rationale

110 As a result of the Third UN Conference on the Law of the Sea, and the establishment of 200-mile Exclusive Economic Zones, coastal States bordering the region gained jurisdiction over large stretches of the ocean, with control of exploitation of living and non-living resources within these areas. In the offshore and deep-sea areas of the Exclusive Economic Zones, as well as in the international waters, the migratory stocks of tuna form the most important living resource.

While some coastal countries with no traditional tuna fisheries of their own would want to take advantage of these resources, other coastal States may need to expand their tuna fisheries beyond the presently exploited coastal areas where there is high exploitation of the resource. Extensions of tuna fishing into new areas of national jurisdiction or the establishment of new tuna fisheries could take place either by coastal States on their own or through the mechanisms of joint ventures, licensing, etc . 111

It is therefore important to obtain information on the extent of tuna stocks in the central Indian Ocean and their distribution in space and time so that coastal States can plan development of fisheries based on these resources. 112

Foreign purse seiners are fishing for skipjack and yellowfin tuna in the international waters and in some EEZ's under license since 1982-1983. There is a possibility of this fishery extending to other parts of the Indian Ocean. 113

Tuna species show clear temperature preferences and cannot withstand oxygen levels below well established limits. The use of the purse-seine in catching surface-dwelling tunas is limited to areas where the thermocline occurs at depths of less than 100 metres. The determination of the thermocline as well as temperature boundaries is therefore of great practical importance to the tuna fleet. Expendable bathythermographs and other methods are already being used from purse seiners to collect oceanographic data. On the other hand, oceanographic data collected by other vessels would be of great practical use to the tuna fleet and fishery scientists to determine areas where tunas might be concentrating and where they would be accessible to surface gear. 114

The oceanographic data collected by tuna vessels will form a significant contribution to the knowledge of the thermal structure of the Indian Ocean, particularly in the central parts not frequently used by ships. Knowledge of the spatial and temporal distribution of tuna populations is quite inadequate and another important source of information is data on abundance and distribution of tuna eggs and larvae. 115

Objectives

The main objectives of this project will be to: 116

- obtain a better knowledge of the temperature distribution in the offshore waters of the central Indian Ocean.

- provide the tuna fleet with oceanograhic information for operational purposes; e.g., for the determination of potential fishing areas.

- advance knowledge of the spatial and temporal distribution and abundance of tuna eggs and larvae.

Observational Requirements

117 To facilitate the proposed investigations, it will be necessary to:

- provide expendable bathythermographs (XBTs) to the tuna fleet;

- provide access of the tuna fleet, at short-notice, to expendable-BT data collected by ships of opportunity;

- set-up facilities for the collection of oceanographic data from the tuna fleet; advantage should be taken of collaboration with an existing project executed by IFREMER (Institut français de Recherche pour l'Exploitation de la Mer).

- obtain ground truth for sea-surface temperature and other data collected via satellites, particularly in relation to tuna distribution; and

- promote extensive quantitative ichthyoplankton sampling, processing and identification of tuna eggs and larvae, and the determination of their temporal and spatial distribution.

(ii) OCEANIC ENVIRONMENT, PELAGIC BIOPRODUCTIVITY AND LIVING RESOURCES OF THE NORTHERN ARABIAN SEA.

Rationale

118 The northern Arabian Sea constitutes a large unique ecosystem within the Indian Ocean. Its oceanographic conditions, which completely reverse in an annual cycle in response to the changes betweeen the north-east and south-west monsoons, are very variable, owing mainly to the influences of the Somali current and inputs of intermediate water masses from the Red Sea, the Gulf and the central Arabian Sea. During the south-west monsoon season, upwelling occurs regularly in many areas. In the most affected areas, its extent is much greater, at the surface and at depth, as is the case with the classic upwelling along the western coasts of Africa and the Americas. Consequently, there is a massive seasonal supply of nutrients into the euphotic zone. However, due to a number of favourable factors, nutrient levels remain sufficient throughout the annual cycle to support a balanced high primary production almost steadily. The zooplanktonic, mainly secondary, productivity is similarly high and steady. Evaluation of currently available data justifies considering these waters as being among the richest not only of the Indian Ocean but also of the world ocean.

119 As far as higher trophic levels are concerned, including exploitable living resources, it is perfectly logical to expect that such trophic potentials support very large stocks of fish, etc. Recent reliable results indicate that this expectation is true of the pelagic zone which certainly contains largely underexploited resources of epipelagic fish (mainly sardines, mackerels, etc) and an immense potential (e.g., 20-30 million tons) of mesopelagic myctophids. However, the stocks of demersal fish appear to be much more limited in certain areas, even showing signs of over-exploitation.

A side effect of the productivity-promoting upwelling is the seasonal appearance of almost anoxic intermediate water masses in subsurface layers (at depths of 20 m or even less). This phenomenon drastically affects the ecosystem in many ways, including large-size migrations and structural recombinations in fish communities, pelagic and demersal. Although there is not much scientific information available, an assumption of hidden fish mortalities seems to be quite justified. 120

The rather formidable phenomena outlined above are only fragmentarily explored and deserve, from the standpoint of fundamental marine science, the highest degree of attention. However, it appears quite clear that the goal of an increased yet rational economic exploitation of the living resources of this extraordinarily variable ecosystem cannot be achieved without an adequate scientific basis. To ensure a minimum scientific basis requires rather complex knowledge resulting from interdisciplinary research on relevant meteorological and physio-chemical processes affecting the pelagic environment at all levels of its bioproductivity and its exploitable resources in particular. 121

Since the northern Arabian Sea must be, by its nature, considered as a functional unit, the needed investigations should, a priori, cover the whole region. However, the area is extensive and the seas, particularly during the summer monsoon, are heavy. Therefore, the needed sea-going research requires a sizeable and well-equipped research vessel, operating continuously year round with an interdisciplinary scientific team aboard. Probably, no single country bordering this area can support alone the relevant capital and running costs, and even if so, this would mean an uneconomic duplication of effort. Therefore, it appears desirable that the countries bordering the region undertake the proposed study under the co-ordination of an appropriate regional body. 122

(iii) INVESTIGATIONS OF EXPLOITABLE DEMERSAL LIVING RESOURCES OF THE DEEP SHELF AND BATHYAL ZONES.

Rationale

The present fisheries for demersal species in the Indian Ocean and adjacent seas are mainly concentrated on shrimps in shallow waters and on reef-fish communities. Governments of countries bordering the area have expressed great interest in a further exploitation of their EEZs by extending the demersal fisheries into deeper water (beyond 50-m depth). Extensive survey work would be needed to cover the entire area. Such survey work could be concentrated, however, in areas where oceanographic conditions are favourable for such resources. 123

There are indications that, in many areas, oxygen levels, sea-bottom conditions and current strengths, may be limiting factors for the harvest of such resources on a year-round basis if at all possible. Since an oceanographic data base can be assembled more cheaply and more quickly than a fishery survey, the co-operation of oceanographers is needed to identify areas where demersal resources may be found and areas where they are unlikely to be found in commercial quantities. 124

Objectives

125 The objectives of this project will be to:

- identify potential areas of harvestable resources at depths below 50 m in the Indian Ocean region;

- demonstrate the abundance, composition and harvestability of demersal resources in selected areas.

Observational Requirements

126 Execution of the proposed research requires at least:

- oceanographic studies on a regional basis co-ordinated by IOC.

- once the positive areas have been identified, exploratory fishing surveys should be conducted with suitable gear (e.g, trawls on smooth bottom, and hook and line or similar gear on rough bottom) by national research vessels and through a regional project, preferably executed by FAO using vessels from the region.

(iv) RESEARCH ON THE ENVIRONMENT AND THE LIVING RESOURCES OF THE RED SEA

Rationale

127 The Red Sea is unique, being a closed · highly saline water body with extended gulfs, notably the Gulfs of Suez and Aqaba. Its connection with the Indian Ocean through the Strait of Bab el-Mandab is also peculiar. It is, moreover, a rift valley and thus characterized by hot brines at the bottom of the rift.

128 The influence of water exchanges between the Red Sea and the Arabian Sea is little known, and these exchanges, which are themselves affected by the monsoons, are believed to affect the productivity and chemical balance of the Red Sea.

Objectives

129 The proposed project should determine:

- the mechanisms controlling primary production in the different areas of the Red Sea;

- the variations in the water-chemistry parameters and the unusual weather conditions affecting the fauna and flora;

- the annual changes in biomass and in the composition of the ichthyoplankton.

Observational Requirements

This project is a long-term one requiring the co-operation of the countries and institutes in the Red Sea Region. 130

Biological and chemical samples should be collected from all parts of the Red Sea, including the Gulf of Suez and the Gulf of Aqaba. Analyses should be done in laboratories in the region or in selected laboratories elsewhere, where expertise is available. 131

The aforementioned project should be carried out with the co-operation and active participation of the Programme on the Environment of the Red Sea and Gulf of Aden (PERSGA) and the Unesco Division of Marine Sciences through the strenghthening of ongoing activities and through new activities carried out by the IOC Programme Group for the Central Indian Ocean. 132

However, before the project proper is initiated, it is advisable to make an inventory of what is going on in the relevant institutions, with special stress on manpower and facilities as well as on the capabilities to carry out specialized research or analysis of data; such an inventory should contain a separate part indentifying training facilities and training needs in the next decade. The preparation of such an inventory requires one or two experts who have wide experience, preferably of the region, to visit the countries of the region to collect the relevant information on the spot. 133

(v) SURVEY OF CORAL-REEF RESOURCES AND STRENGTHENING OF REGIONAL CO-OPERATION IN TRAINING AND DATA EXCHANGE.

Rationale

Shallow-water marine habitats, such as coral reefs and seagrass beds, are not only of considerable scientific interest but have enormous economic value. This arises because: 134

(a) Coral reefs and seagrass beds are highly productive (i.e., they produce large quantities of those plant materials that directly or indirectly support all marine invertebrates and fish. Coral reefs and seagrass beds may be a hundred times more productive than equivalent areas of open tropical ocean. In many countries of the region, a substantial proportion of all fish, even though caught in the open sea, may be dependent on these habitats for their food. If the habitats are destroyed, these fish stocks will be severely affected or drastically reduced.

(b) These habitats are also critical spawning and nursery grounds for several commercial species of fish, shrimp and molluscs.

(c) These habitats, especially coral reefs, are of particular importance to the tourist industries of several Indian Ocean countries.

(d) Coral reefs act as barriers to waves and storm surges, protecting coastlines and coastal roads and buildings against erosion by the sea. Sea grasses also help in the consolidation of shallow-water sea beds.

(e) Coral reefs are increasingly important to the recreational needs of local people who, in many countries, are using the coast for relaxation, snorkelling, Scuba diving etc.

(f) Coral reefs are considered to be store-houses of compounds of potential medicinal importance, since many marine invertebrates secrete antibiotics and other biochemical compounds to protect themselves.

(g) Sea grass beds are the feeding grounds of several endangered animals such as the dugong and several species of turtles.

135 Despite their economic and social value, and because of the increasing pace of development, and a general lack of knowledge of the underwater environment, coral reefs and other important habitats are being damaged or destroyed at an alarming rate throughout the region. This damage is principally caused by:

(a) sedimentation - sediment arising from dredging, land-fill operations and especially inland soil erosion settles on reefs killing the coral, often at considerable distances from the source of the sediment;

(b) mining of coral reefs for building materials and lime;

(c) destructive fishing practices, especially dynamiting;

(d) infestations of Crown-of-Thorns starfish (Acanthaster planci) and reef-eroding sea urchins, possibly related to man's effect on the ecological balance of the reef;

and, in some areas, the following factors are important in causing reef degradation:

(e) unregulated tourist activities, including damage by anchors, walking on corals, collecting shells and corals;

(f) overfishing for commercial species and aquarium fish;

(g) chronic low-level oil pollution; and

(h) various forms of non-oil pollution.

136 A principal problem is that, in many countries, planners and environmental managers do not know the exact extent and whereabouts under water of the most important areas of productive habitat, and are unaware of the extent of damage and degradation. Given this information, logical steps can be taken to plan coastal development etc., so as to avoid damaging areas important to fisheries, tourism, recreation etc. Priorities for national authorities and agencies may thus include:

(a) mapping in detail the occurrence and extent of critical habitats, spawning grounds, etc;

(b) assessing the extent of existing impacts causing deterioration of these habitats;

(c) establishing coastal zoning schemes so that areas important to fisheries, recreation, tourism etc. are protected from development and destructive practices; more important areas should be established as fishery management areas, protected sites and national (marine) parks etc., and their resources managed in a sustainable manner; and

(d) establishing rational standards to control discharge of pollutants and sediment etc.

However, few of the countries of the region yet have sufficient resources or sufficient trained scientific manpower to carry out such work unaided. Unesco, particularly within its COMAR project, has held training courses, workshops and symposia, and published a series of manuals on research and survey methods for coral reefs, mangroves and seagrasses. Some countries are receiving assistance with survey and management work as a result of bilateral agreements or with the support of the international agencies, such as Unesco, IOC, UNEP and the International Union for Conservation of Nature and Natural Resources (IUCN), which has recently published a Directory of Indian Ocean Coral Reefs. 137

Therefore, it is highly desirable that the international agencies concerned - particularly the IOC, through its Programme Group for INCINDIO, Unesco, through COMAR, UNEP, IUCN, PERSGA and ROPME give priority within their respective programmes to hastening actual surveys of the precise extent and state of reef resources in countries or areas where such knowledge is lacking or incomplete, and to promoting co-operation within the region in survey work and training. 138

Objectives

The objectives of the proposed project will be: 139

- support the actual work of surveying and planning in some countries of the region;

- strengthen national capabilities by providing on-the-job training and experience for scientists from the region;

- promote regional co-operation (e.g., to optimize the effective use of the limited number of specialists with the taxonomic and ecological expertise);

- produce set(s) of habitat maps (or an atlas) for the country(s) or area(s) selected for the model survey(s);

- prepare report(s) on the distribution and condition of habitats and species, especially species of commercial and scientific interest, within the area(s) surveyed;

- produce a booklet or short manual giving recommended procedures for surveying and mapping reefs and associated habitats, with reference to the more specialized Unesco monograph on Coral Reefs: Research Methods, and the Unesco Handbook of Coral Reef Management;

- make management recommendations for the areas studied.

Observational Requirements

140 Model surveys of the distribution of coral reefs (together with associated seagrass) in one or more of the countries of the region, leading to the development of model coastal-zone management plans, are required.

141 The survey(s) should bring together a team of experts from different parts of the region (along with consultants required from outside the region) to further develop and standardize the methods required for such extensive survey work.

142 Younger scientists from different countries of the region should be involved in the survey(s) to provide them with training and experience of such methods (the data collected provide a suitable basis for postgraduate work).

143 Such surveys should include investigation of prevailing levels of sedimentation affecting each reef area, and should be complemented by assessment of the economic value and scientific value of coral-reef ecosystems.

144 Informal links between working coral-reef scientists and managers should be promoted by the concerned agencies to facilitate exchange of information and expertise, and to contribute to the expansion of a regional data base on coral reefs, such as is provided by the IUCN Indian Ocean Coral-reef Directory.

145 Methods that would need to be used within the surveys would include:

- use of satellite imagery;

- use of serial photography;

- ground truthing at appropriate intervals using rapid assessment techniques;

- more detailed quantitative surveys at wider intervals (say 20 km) for particularly significant sites;

- use of a microcomputer for the handling and analysis of data and the generation of data products.

(vi) RED TIDES IN THE CENTRAL INDIAN OCEAN AND ADJACENT SEAS AND GULFS

Rationale

Red tides are blooms of unicellular marine planktonic algae which become so dense that they discolour the sea (e.g., Red Sea). These events attract much public attention as a result of their potential economic and social effects, and knowledge of the autecology of the plankton species involved is crucial to understanding and controlling the blooms. 146

The majority of red tides in the central Indian Ocean are basically harmless events (e.g., the blue-green alga Trichodesmium, the dinoflagellates Noctiluca scintillans and Gonyaulax polygramma, the prymnesiophyte Phaeocystis) and only in exceptional cases have such plankton blooms caused fish kills by generation of anoxic conditions. Moderate coastal engineering is suggested as a viable option to combat recurrent anoxic events in sheltered bays. The raphidophyte flagellate Chattonella has caused episodic fish kills by releasing free fatty acids in the sea water which destroy the gill tissues of fish. There is evidence that some red-tide problems (e.g., Chattonella, Noctiluca) are aggravated by industrial eutrophication, but other plankton blooms (e.g., Trichodesmium) should be regarded as completely natural events. 147

Red tides due to toxic dinoflagellates, which produce neurotoxins that can find their way through fish and shellfish to man, are well documented from Europe, North America and Japan. At present, paralytic shellfish poisoning (PSP), diarrhoetic shellfish poisoning (DSP) and ciguatera fish poisoning are virtually unknown from the central Indian Ocean. Admittedly, surveys for the causative dinoflagellate species have been inadequate and ethnic dietary habits (e.g., low shellfish consumption) may also play a role. Attention is drawn to the apparent spreading of Pyrodinium bahamense var. compressa (PSP) through the East Indies (Papua New Guinea, Philippines, Malaysia, Indonesia), and Protogonyaulax tamarensis has caused recent PSP fatalities in Thailand. The latter problems are adequately dealt with at present by a Study Group on Red Tides under the IOC Programme Group for the Western Pacific. 148

Objectives

The objectives of this project will be to: 149

- organize a basic training workshop so that local workers charged with microscopic plankton taxonomy will be capable of recognizing potentially toxic species and their benthic cysts in the Indian ocean region;

- make public health officials aware of the symptoms of various types of shellfish and fish poisoning to ensure that, if necessary, warnings can be issued promptly and effectively.

(vii) TAXONOMIC RESEARCH ON MARINE FAUNA AND FLORA OF THE INDIAN OCEAN

Rationale

150 Almost all the research projects proposed above include ecosystem studies as a more or less dominating component which inevitably requires analyses of the composition and structure of communities. This requirement leads to the well known problems of tedious processing and sorting out of biological samples, and highly demanding taxonomic identifications, ultimately at the species level. Tropical marine biota present, in this respect, a particularly difficult task because of their formidable diversity in the first place. Moreover, a great majority of research institutions working in tropical zones are in developing countries; this is typically the case of the Indian Ocean. Therefore, the availability of facilities is an important factor, and skilled taxonomists are extremely rare. In addition, the taxonomic literature is very difficult to define because its important part comprises old classic works and problems scattered throughout numerous periodicals. These factors have impeded the taxonomy of the region's flora and fauna, but it is essential to the development of the marine biology and biological oceanography in the Indian Ocean, and a special effort is needed to reduce this deficiency.

151 Owing to the importance of the natural resources in the ROPME area, there is a particular and urgent need for taxonomic work in this region.

Objectives

152 To promote relevant improvements, it is proposed to initiate, with international support and by other means, the following actions:

- gradual preparation of taxonomic bibliographies for the tropical zones of the Indian Ocean;
- compilation of an inventory of active specialists working on fauna and flora in the area;
- initiation of the production of identification manuals for the most important taxonomic groups;
- designation of relevant focal points within the existing research institutions in the region;
- encouragement of a group of leading taxonomists to prepare and publish an introductory guide book on Indian Ocean flora and fauna.

Observational Requirements

Marine research institutions in the region must assess their respective needs for taxonomic expertise. Biological samples need to be assessed to determine which genera and/or species cannot be defined at source and arrangements made to obtain authoritative identification. ROPME, in collaboration with relevant international organizations, particularly Unesco, agreed to take the lead in organizing the required expertise. 153

3.5 OCEAN SCIENCE AND NON-LIVING RESOURCES

The Workshop briefly reviewed current knowledge of the Indian Ocean as a basis for drawing up project proposals and recommendations. 154

(i) Geological-Geophysical Mapping

Several stages can be distinguished in the history of geological-geophysical mapping of the Indian Ocean. Data on bottom relief and sediment distribution were the prime interest in the first stage; then, data on magnetic properties, gravities, continuous seismic profiling and other parameters were also considered in the mapping. 155

Some maps, particularly the 3rd edition of the General Bathymetric Chart of the Oceans (GEBCO), were published with results from the first stage, which lasted from the middle of the 19th to the fourth decade of the 20th century. 156

After World War II, research was restarted and this is the second stage. New techniques were used, and some expeditions, including investigations during the International Geophysical Year (1957-58), were organized. As in the first stage, the data were sparse and maps compiled from them were very schematic. 157

An important new stage in oceanic research covered the period 1960-1965 corresponding to the International Indian Ocean Expedition (IIOE). More than 20 countries participated in this Expedition. Some important geographical discoveries were made, and the main orographic scheme became clear for the first time. Since then, it has served as the basis for further survey of distinct features. The results of the IIOE appeared in the maps of the International Geological-Geophysical Atlas of the Indian Ocean, (1975). Tracks plotted on the maps reflected the state of the knowledge, which allowed users to distinguish between the real data and their interpretation. 158

159 New maps also include the new data obtained after IIOE, when parts of other international projects (Upper Mantle Project and Deep Sea Drilling Project) were carried out in the Indian Ocean. Research on rift zones within the Upper Mantle Project marked the beginning of a new stage which included detailed surveys of prefixed areas (Polygons). Such investigations of separate areas by a complex of different methods were carried out in recent years in the Red Sea and Bay of Bengal, on the continental margins of India and Australia, on the Central and Wharton Basins, etc.

160 As a result, bathymetric, magnetic, gravity, geological and other charts were compiled for some features and regions, and some tectonic maps - for the whole ocean or large parts of it - were prepared; the GEBCO 5th edition (published in 1982) and the International Tectonic Map of the World (presented at the International Geological Congress, Moscow, 1984) show the progress in our knowledge.

161 For the Red Sea in particular, a continuous analysis of the northern domain has been made for the marine and the continental areas. A 1:1 000 000-scale bathymetric chart has been drawn from GEBCO plotting sheets, correlated with marine charts from the Service Hydrographique de la Marine (France). The Red Sea morphology is described in the structural framework of this domain, together with a three-dimensional visualization of the sea-floor relief. The orientation and depth variation of the axial valley are shown, with the presence of submarine deeps. The main characteristics of the marginal shelf are confirmed in the morphology and in the lithological and sedimentary structure.

(ii) Geological Evolution

162 The development of the Indian Ocean can be said to have begun about 210 million years ago with the initial break-up of the supercontinent of Pangaea. During the course of the development of the Indian Ocean, palaeogeographic events, such as the separation of Australia-Antarctica from Africa, and the final split between Australia and Antarctica, were all significant threshold events that occurred between 170 and 90 million years ago. The most important event that led to the development of the present-day Indian Ocean and the closure of Tethys was, however, the rapid flight of India northward towards Asia, which began some 80 million years ago. The circulatory and climatic patterns during these developments differed significantly from the modern patterns and were strongly influenced by continental positions, and the opening and closing of surface and deep oceanic passageways. The patterns of sedimentation were in turn influenced by the changing hydrographic and climatic patterns.

The evidence for the development of the Indian ocean is based on geophysical, sedimentary and palaeontological evidence from the deep sea, as well as on stratigraphic data from the continents surrounding the Indian Ocean. However, the data base is still relatively limited in scope and much work needs to be done to fill the major gaps in our knowledge. 163

(iii) River Input into the Indian Ocean

An estimated 60 to 70 percent of the terrigenous sediment entering the oceans comes from the rivers draining southern Asia and the high-standing islands in the Indo-Pacific Ocean. The Ganges-Brahmaputra is the world's largest river system in terms of sediment discharge, and the Irrawady and Indus also rank amongst the major rivers (although the Indus is presently dammed). Perhaps most underrated, however, are those island rivers that are still not documented in western literature. The large sediment input throughout much of the northern and eastern Indian Ocean has meant that many coastal areas are accreting or at least able to withstand local erosion. Decisions by many countries to dam these large rivers may mean that the sediment flux to the ocean will decrease. Decreased sediment supply should imply increased coastal erosion, often with catastrophic results for coastal towns and cities. However, experience with other abandoned river deltas suggests that the erosion may have maximum impact only many years after dam construction has been completed. 164

(iv) Mineral Resources

The sea floor of the Indian Ocean and the continental margins bordering the Ocean are covered by a wide variety of terrigenous, biotic and chemical mineral deposits. Terrigenous heavy-mineral placers are known from the beaches of South Africa (ilmenite, rutile, monazite and zircon), Mozambique (ilmenite, zircon, rutile, garnet and monazite), Tanzania (garnet, ilmenite, kyanite, zircon, magnetite and monazite), western India (ilmenite, rutile, zircon, magnetite, garnet and monazite), Sri Lanka (ilmenite, rutile, monazite, zircon and garnet), Malaysia (tin), Burma (monazite and zircon), Indonesia (tin, ilmenite, titaniferous magnetite, monazite and zircon) and western Australia (rutile. ilmenite, zircon, garnet and monazite). The exploration of these deposits offshore has also been carried out and the results have been particularly encouraging off Mozambique, western India, Sri Lanka, Malaysia and western Australia. The humid tropical climate of some of the land areas bordering the Indian Ocean accelerates weathering of the source rocks. This, coupled with the large river run-off and wave and current conditions, favours the formation of a variety of placer deposits. The beach and offshore placer deposits of the Indian Ocean may be among the largest in the world. 165

The biotic deposits in the Indian Ocean comprise the corals on shallow banks and on the continental shelves, and the 166 oozes in the deep sea. Such deposits are a low-priced commodity and are likely to be exploited only in coastal areas for local construction, cement and chemicals, where onshore limestone deposits are not available. A minor use of shells and corals is for semi-precious jewelry and other ornamental purposes. It is unlikely that the deep-sea oozes will be exploited in the near future. The deposits of calcareous sands, shells and corals are being exploited on a large scale in India for the manufacture of cement, and exploration in some of the areas has indicated reserves of over a thousand million tons.. It is expected that, in many countries, especially the islands whose economies are largely dependent on tourism, restraint would be exercised in the exploitation of these deposits. A study of the deposits would undoubtedly lead to a better understanding of their formation, turnover, regeneration rates and substainable yields, and in turn to their better management. Such a study must, however, consider the potential environmental effects the extraction of minerals, corals etc. may have.

167 The chemical deposits in the Indian Ocean comprise the phosphorites and the polymetallic nodules. Occurrences of phosphorite deposits in the Indian Ocean are reported from the continental margins (South Africa and western India) and the seamounts (eastern and western Indian Ocean). The continental margins of South Africa, East Africa, southern Arabia, western India and the Andaman Islands are marked by strong upwelling as being non-depositional environments that are conducive to the formation of phosphorites. The onshore deposits are sufficient to meet requirements in the near future. The exploitation of the marine deposits would be feasible in certain coastal areas where the cost of imported fertilizers and transport can offset the higher cost of marine mining. The exploitation of the deposits even in the future would provide a significant input to the dominantly agricultural economies of many of the countries in the Indian Ocean.

168 The polymetallic nodules in the Indian Ocean cover an area of 10-15 million square kilometres and the resources are estimated to be about 0.17 trillion tonnes. A study of over 900 chemical analyses from 350 stations shows that the deposits in most of the basins are submarginal. The deposits in the central Indian Ocean may only be categorized as paramarginal (Ni + Cu + Co over 2.47 per cent and abundance over 5 kg/m^2 . The exploration of submarginal deposits may, however, lead to the identification of potential areas for later development. Estimates of reserves of polymetallic massive sulphides, which form in the mid-ocean ridge-crest areas, cannot be given here, since little research work has been done on them so far.

169 In considering research projects for the central and northern Indian Ocean and adjacent seas and gulfs, with respect to non-living resources, the Workshop stressed the distinct methodological separation between work on continental

margins of the coastal countries and research in the deeper parts of the Indian Ocean basins. The former work in shallower areas of the continental shelf and slope is obviously the most meaningful and practical from the coastal countries' point of view. But some of the most important and scientifically rewarding problems are in the deep ocean, often beyond the practical capabilities of most of the regional countries at this time.

Therefore, the Workshop identified several near-shore coastal and continental-margin problems that can be tackled co-operatively by the regional countries, in the framework of IOCINDIO in co-operation with other interested organizations. 170

The Workshop agreed that research on the non-living resources of the oceans (minerals, oil and gas) has already been adequately formulated in the Report of the First Session of IOC-UN (OETB) Guiding Group of Experts on Ocean Science in Relation to Non-living Resources (OSNLR), and that the recommendations contained therein apply equally well to the central Indian Ocean. The Workshop strongly endorsed them as a basis for the regional components of OSNLR as part of the programme of work of the IOC Programme Group for the Central Indian Ocean. Those OSLNR recommendations are not repeated here but are supplemented by general guidelines for the selection and promotion of specific research projects for IOCINDIO, as follows. 171

(i) <u>SURVEY OF CONTINENTAL SHELVES</u>

Highest priority should be given to the geological surveying of selected areas of the shallower parts of the continental margins, to provide an evaluation of their economic mineral potential (e.g., heavy minerals, phosphate), and to increase knowledge and understanding of coastal geological processes, such as coastal erosion, longshore and nearshore sediment transport, reef growth and destruction. Knowledge of the effects of changes in the drainage systems on land, as well as of the pollution of the sea by human activity, will be a desirable by-product. Understanding of the shallow-water geological processes may help to predict and perhaps avoid hazardous changes in the environment when the sea floor is subjected to extraction or destruction (e.g., breaking of fringe reefs by wave activity or mineral extraction). Shallow-water geological surveying is relatively inexpensive and can often be easily undertaken by coastal nations on their own; however, through regional or sub-regional co-operation involving the sharing of methods, results and, possibly, equipment and vessels, the gain in knowledge and understanding can generally be greatly accelerated. 172

(ii) <u>COASTAL PROCESSES</u>

Studies of coastal processes, such as the effects of waves, tides and storm-surges on erosion, transportation and deposition of sediments, should be undertaken or continued in all coastal countries. These processes should be studied especially where they might affect human life, stability and safety of coastal 173 structures and the maintainence of harbour entrances, but they should also be studied in more remote areas in order to understand the interrelationships of an entire regional coast. Any disruption of natural coastal processes by the influence of man can have effects far away. Effects of pumping of ground water or oil and gas can significantly increase rates of coastal subsidence which, in turn, affects flooding, erosion, invasion of fresh water aquifers by salt water, and the stability of buildings. Action based on the aforementioned studies and resulting recommendations can be taken only by the appropriate local and state authorities, but these authorities must be informed and properly advised by the scientists and engineers undertaking the studies. Therefore, the responsibility of scientists and engineers does not end with the completion of their reports.

(iii) EFFECTS OF DAMMING RIVERS

174 Another imnportant problem for the regional countries, and one that can be tackled within the IOCINDIO framework, is the effect of upstream damming of rivers on the coastal regimes. The damming of a river, such as the Indus, has had short-term observable detrimental effects on the mangrove ecosystem, fisheries, and longshore sedimentation, and has led to increased pollution of the harbours and has accelerated coastal ersoion. A concerted effort needs to be made to study further the short-term and the long-term effects of such damming and to begin to quantify the effects of these activities on the deltas. Some of the specific studies required are:

- Detailed analysis of tide-gauge records, which can point to the sea-level changes in the delta. If such wave-gauge stations do not exist, they need to be established.

- Accurate description of flow patterns and sediment loads of rivers (before and after the damming).

- Careful comparison of old maps and satellite imagery may make it possible to determine recent erosion and accretion patterns in the deltas. Only after such information is available will it be possible to determine the long-term effects on the coastal regimes and predict which areas might be particularly severely affected in the coming decades. The Mahaweli River in Sri Lanka and the Indus River in Pakistan have been dammed relatively recently, and their study could lead to an understanding of the impact of this important human activity (damming) on the deltas and the coasts. Such studies should be undertaken either regionally or in co-operation with interested international agencies.

(iv) DEEP-WATER SEDIMENTS

175 As mentioned earlier, from the scientific point of view, some of the most rewarding research projects concern the deep ocean and are often remote and/or require instrumentation and technical manpower that may not be available locally or regionally in the coastal countries. A good example of such a project is the study of the Arabian Sea sedimentary, oceanographic and climatic history.

The collision of the Indian plate with Eurasia, the uplift of the Himalayas and the beginning of the development of the Indus and Bengal fans, the initiation of the cyclic monsoonal-type oceanic and atmospheric circulation, and the beginning of high productivity along the coasts of Arabian Sea countries, are all important scientific issues. Such problems can only be studied by extensive drilling to recover the sediments of relevant ages and by studies of the physical and chemical properties of water masses and their biota and suspended matter. For example, to better understand the mechanisms and physicochemical constraints of the vertical transport of suspended matter in the oceans, and its accumulation as sediment, requires the long-term deployment of sediment traps and recovery of long box-cores. Investigation of the chemical, mineralogical and biological composition of samples from the water and sediment columns will also help in understanding how biological primary production, as well as fluviatile and aeolian inputs, are dependent on the circulation patterns in the atmosphere and the ocean, and particularly on monsoonal influences. Such research is planned over wide areas of the Indian Ocean for the next 2-3 years by international research organizations, such as the Ocean Drilling Programme (ODP) consortium, as well as by numerous national research organizations (e.g., in the Federal Republic of Germany, the UK and the USA). Participation by scientists from the coastal nations in these ongoing or planned projects is one of the most effective ways of training personnel and of collecting information and data about the region. It also provides excellent opportunities to contribute to important scientific programmes (see item (vi) below).

The Workshop strongly urged the nations within the IOCINDIO region to participate actively in international research programmes and make full use of the scientific opportunities they represent. The role of IOC, in facilitating communication and regional co-operation in such projects, is a central one and is discussed in more detail below. 176

(v) <u>STUDIES OF CRUSTAL STRUCTURE, TECTONICS AND GEOLOGICAL EVOLUTION</u>

Such studies generally require deep-water geophysical surveying and geological sampling with large and expensive oceanographic ships, which are at present outside the capabilities and objectives of many Indian Ocean coastal countries. Expeditions from other nations and oceanographic research institutions will, however, be operating in international waters of the Indian Ocean during the coming years as they have in the past, endeavoring to solve these problems. Collaboration in these projects and participation in the work at sea and in the processing and analysis of the data are already normal practice. Qualified geologists and geophysicists should take advantage of these opportunities. Examples of these expeditions and presently planned and funded surveys preparatory to the Ocean Drilling Programme work are described below. 177

SUPPORTING RECOMMENDATIONS

178 The Ocean Drilling Programme: This is a consortium that operates the drilling ship JOIDES RESOLUTION for deep-sea scientific drilling. ODP members are the USA, the Federal Republic of Germany, France, Canada and Japan. Tentative plans for drilling in the Indian Ocean in 1987 and 1988 are as follows:

1987 June-July: A decision will be made on drilling in the following areas: Davie Ridge, Somali Basin, SW Indian Ridge or the Makran subduction accretion complex.

1987 August-September: Red Sea

1987 October-November: Arabian Sea Neogene palaeo-oceanography.

1987 December, 1988 January-February-March: Kerguelen Plateau.

1988 April-May: S. Ninety East and Broken Ridges.

1988 June-July: N. Ninety East Ridge, zone of intraplate deformation and distal Bengal Fan.

1988 August-September: NW Australian margin.

179 Detailed Mapping: There have been no revisions of the main geological/geophysical maps of the region until the publication of the International Indian Ocean Geological/Geophysical Atlas (in 1975) and GEBCO Sheet 05. The Workshop therefore welcomed the plans for an International Bathymetric Chart of the Western Indian Ocean (IBCWIO) under the aegis of IOC and in the framework of its Programme Group for the Northern and Central Western Indian Ocean. With regard to the need for more detailed and larger-scale charts in support of future OSNLR projects, the Workshop recommended that the possibility of making such maps for the IOCINDIO region be investigated, with the collaboration of the Guiding Committee for GEBCO.

180 The Role of IOC: The Workshop agreed that the IOC has a central role as a clearing-house of information that will foster greater participation of scientists from the Indian Ocean region in international and national research projects as outlined above. Cruise information is often not easily available and the distribution of prior knowledge of such plans to research organizations in the region could be of utmost value. For example, for the next three years, important cruises in the region are planned by the USA (including site-survey cruises preparatory to ODP drilling), the UK and the Federal Republic of Germany (the latter plans bilateral work with India in the region). In addition, plans for ODP drilling include numerous cruises in the central and northern Indian Ocean as well as in the Red Sea. Cruise information from these and other sources should be actively

gathered by the IOC and supplied to relevant organizations in the region. IOC can also help in facilitating contacts and in pre- and post-cruise training and research by scientists from the region at international laboratories. The co-ordination of the proposed projects and the aforementioned supporting activities could be carried out through the IOC Programme Group for the Central Indian Ocean in collaboration with the IOC Programme Group for the Northern and Central Western Indian Ocean.

Training Opportunities: The Workshop stressed the fact that the deep-sea projects of various international organizations, notably in the framework of the Ocean Drilling Programme, as noted above, provide numerous opportunities for regional scientists and technicians to participate. The Workshop called on the IOC and Unesco to assist in arranging for such participation, as well as training for coastal marine geologists and technicians. 181

3.6 MARINE POLLUTION RESEARCH AND MONITORING

In the Central Indian Ocean region as a whole the level of pollution is not regarded as being serious, and confined to coastal areas rather than the offshore oceanic waters. 182

Agriculture, industry and in some cases mining, are, however, important economic bases for the countries, and effects of pollution in the coastal marine environment from such activities have appeared. Although the effects at present are confined to coastal areas, they may have far-reaching consequences on several countries due to the prevailing wind system and the characteristics of the water circulation in the region. 183

The main types of pollution are sediment load, organic and nutrient load and oil. Sediment load is a result of increased land erosion and coastal dredging and dumping operations, notably in the Bay of Bengal, the Andaman Sea and the Straits of Malacca. This has shown significant impacts on the coral-reef ecosystems, oyster and other shellfish beds and, to some extent, on fish migrations, particularly the spawning migrations into estuarine areas of rivers. Organic load is mainly due to the discharge of increasing quantities of untreated sewage, particularly in areas of higher population density, and to the discharge of copious amounts of livestock wastes directly into the coastal aquatic regime or indirectly through riverine discharges. 184

The large river inflows are often badly polluted. Nutrient load is a result of domestic detergents and the leaching of fertilizer from agricultural lands. Organic and nutrient loads generate tremendous demands for oxygen in the water, through the development of planktonic blooms in coastal waters. 185

186 Oil pollution is a chronic and sometimes acute problem in and around many harbours in most countries of the region. The effects of oil spills are seen on many beaches in the form of deposits of tar-like residues. Oil pollution is brought about by increasing numbers of merchant vessels operationally discharging oily bilge, and by oil tankers, through tank washings and maritime accidents. Apart from these, there are other sources of oil pollution, such as those from sea-bed exploration, sea-bed pipelines and shore installations. The indiscriminate use of dispersants to combat oil pollution can have considerable environmental impact, particularly on the sensitive egg and larval stages of marine life. Besides the above-mentioned major pollution problems, there are others, such as bacterial contamination of shellfish resulting from organic load in water in areas of high population density, and the persistent pollutants, such as heavy metals and chlorinated hydrocarbons (including the polychlorinated biphenyls), which are becoming a growing threat to the marine environment, especially as a result of industrialization. Added to that, it should be emphasized here that sea-bed mining for tin and other minerals is envisaged in the near future, and these activities can bring about major environmental problems. Thermal pollution is building up in some areas of coastal seas as a result of development of power plants and liquid natural gas (LNG) plants. This type of pollution should not be allowed to increase coastal water temperatures significantly, since life in tropical seas is living at the uppermost limits of temperature tolerance, and any further increase in water temperatures could bring about serious threats to their existence. Coral reefs occur in many areas of the Indian Ocean and provide an important economic input in many cases. Damage can occur through over-exploitation and through effects of pollution. Some reefs have died owing to the impact of pollutants, particularly from oil spills. Mangroves constitute a resource in many areas, by contributing nutrients, by being spawning, nursery and feeding grounds for economically important species, by providing protection to sensitive communities like coral reefs, and by providing material for various uses by the local population. The mangroves also influence the sediment characteristics, the local mean sea level and the water courses. Coral reefs and mangroves constitute particularly sensitive or vulnerable areas, worthy of protection, management and control. An aesthetic problem in many countries of the Region arises partly because a large part of the population lacks adequate sanitary services; the tidal characteristics imply that large littoral areas are exposed during low tides, are unpleasant and may constitute health hazards.

187 The Workshop was also informed of IOC's global programmes and activities in this field. Overall co-ordination lies with the IOC Working Committee for the Global Investigation of Polution in the Marine Environment (GIPME). This Working Committee has two important Groups of Experts, one on Methods, Standards and Intercalibration (GEMSI), and another on the Effects of Pollutants (GEEP). GEMSI develops analytical methods (and manuals thereon)

for use in the IOC Marine Pollution Monitoring System (MARPOLMON) and is co-sponsored by UNEP. GEMSI is also currently studying the problems of making analytical standards available to marine institutions and of intercalibration of analyses. GEEP is trying to develop the scientific basis for the determination of the vulnerability of particular areas to marine pollutants.

RECOMMENDATIONS

To deal with these questions there is a need for infrastructure development and for toxicity screening to monitor potential pollution problems in the region. 188

The Workshop recognized that coastal marine pollution is a significant problem, but that each situation needs to be considered on its own merits, provided expert technical guidance can be made available when required. It recognized that a considerable amount of advice is available from GEMSI. 189

The Workshop recommended the promotion of regional components of the IOC Marine Pollution Monitoring System (MARPOLMON) to be implemented by laboratories active in this field and supported by adequate training and intercalibration. It recommended doing this in collaboration with UNEP and, in their respective regions, ROPME and PERSGA. 190

The Workshop also considered the possibility of preparing environmental sensivity index maps of selected coastal areas but concluded that, while such maps were undeniably useful, the state of knowledge of the coastal marine environment was, in many countries, not sufficiently advanced to make the proposal widely feasible. 191

4. OCEAN SERVICE REQUIREMENTS FOR FUTURE SCIENTIFIC CO-OPERATION

4.1 INTERNATIONAL OCEANOGRAPHIC DATA EXCHANGE (IODE) AND MARINE INFORMATION MANAGEMENT (MIM)

The IODE system is at present the only international mechanism that permits the worldwide diffusion of oceanographic data and information and their archiving in two World Data Centres (WDCs A and B, Oceanography). These centres send any set of available data upon request. 192

However, far from all of the existing data is provided to these centres and a strong effort should be made by the data - gathering organizations to use the IODE system for data exchange and archiving. 193

The establishment of National Oceanographic Data Centres (NODCs) is desirable and of high benefit for the region. The amount of data available is expected to increase tremendously in 194 the next decade, particularly with the future satellites, and the information will be much better utilized by the region if adequate capability of data assimilation is available.

195 Several NODCs already exist or are planned in the region. They represent, however, considerable investment and require advanced technology and scientific expertise. Financial support and training is necessary for most of the countries of the IOCINDIO region to enable them to establish or develop efficient NODCs able to assume regional and international responsibilities.

196 In the framework of IODE, the IOC, FAO and the UN(OETB) collaborate in the promotion of the Aquatic Sciences and Fisheries Information System (ASFIS) which provides several products, notably the Aquatic Sciences and Fisheries Abstracts (ASFA) and Marine Science Contents Tables (MSCT).

197 The Workshop stressed the importance of international data exchange, since it made a much greater quantity of data, on a particular marine scientific subject, available to individuals and institutions. It agreed that it was important, within reasonable limits, to ensure right of first use to the originator.

198 The Workshop recognized the need to assist institutions in building up their libraries and information/documentation services and to promote the necessary exchange of information and documentation at the regional level.

199 The Workshop also stressed the need for training in the fields of data exchange and marine information management, as a means of developing IODE in the region, particularly to meet the needs of the Member States of the Programme Group for IOCINDIO.

5. TRAINING, EDUCATION AND MUTUAL ASSISTANCE (TEMA) IN SUPPORT OF PROPOSED SCIENTIFIC RESEARCH PROJECTS

200 The Secretary of IOC briefly reviewed current developments in the implementation of the Unesco-IOC Comprehensive Plan for a Major Assistance Programme to Enhance the Marine Science Capabilities of Developing Countries. This Plan represents a new dimension to the longstanding IOC programme of Training, Education and Mutual Assistance in the Marine Sciences (TEMA) and the related activities undertaken by the Unesco Division of Marine Sciences.

201 The Comprehensive Plan calls for the preparation of Marine Science Country profiles as a means of defining present national marine and scientific requirements and, thus, the needs to enable such infrastructure to develop. A few Member States in the region have initiated preparation of such Profiles.

Another major initiative under the Plan is the proposal to Member States to establish, if not existing, National Oceanographic Commissions or similar high-level bodies charged with co-ordinating national marine scientific research and acting as the national liaison with IOC in this field; or the strengthening, if necessary, of such bodies, if existing. 202

The third major initiative is the development of regional or subregional technical assistance projects to develop marine science capabilities with extrabudgetary funding. 203

One aspect of the development of marine science capabilities at the national and regional levels is the improved use of research vessels, and the recommendations of the IOC-FAO Workshop on this subject (Lisbon, 4-6 May 1984) may be relevant to the work of the Programme Group for IOCINDIO. 204

The Workshop welcomed these various initiatives of the IOC and Unesco. It noted that general recommendations for training in relation to project proposals considered under the various sections of the present report had been made by the participants. The Workshop stressed the importance of developing the training element of each of the adopted projects so that specific proposals could be submitted to the First Session of the Programme Group for the Central Indian Ocean. 205

6. BASIS FOR THE FUNCTIONS OF THE PROGRAMME GROUP

The Technical Secretary introduced Documents IOC/WCIO/8 (Guidelines for the Terms of Reference and Geographical Coverage of IOCINDIO) and IOC/WC10/8 Add. which indicated the general nature of Terms of Reference for the Programme Group. The Technical Secretary briefly reviewed the general criteria for the creation of any IOC regional subsidiary body and the basic but non-specific Terms of Reference for IOC Programme Groups. 206

6.1 PROPOSALS FOR THE TERMS OF REFERENCE

The Technical Secretary outlined the present Terms of Reference for the two IOC Programme Groups that geographically interface with the Programme Group for the Central Indian Ocean: that for the North and Central Western Indian Ocean and that for the Western Pacific. He invited the participants to indicate any specific guidelines that should be incorporated, while stressing that it was not expected of the Workshop that it draft and adopt any Terms of Reference, this being a task for the Programme Group. 207

The Workshop generally stressed the importance of the scientists' viewpoint which recognized the fundamental differences between the central Indian Ocean and the western Pacific, so that the Terms of Reference for a regional subsidiary body should reflect such differences. It also stressed the importance of co-operation with other appropriate regional bodies, the promotion of data and information exchange, the 208 organization of scientific meetings and the exchange of scientists between institutions participating in a particular programme. The Workshop requested the IOC to ensure that these concepts were embodied in the final Terms of Reference.

6.2 GEOGRAPHICAL LIMITS

209 The Technical Secretary informed the Workshop that, normally, precise geographical boundaries are not fixed for IOC regional subsidiary bodies. There are several reasons for this: first, these bodies are charged with developing and carrying out, inter alia, international co-operative marine research, and the phenomena that are the subjects of such research are not bound by geographical co-ordinates; second, there is no precise definition of membership (e.g., "open to all interested Member States", in the case of WESTPAC, or "open to Member States of the IOCINDIO region and to other interested Member States of the Commission", in the case of IOCINDIO); if a Member State of a given region does not participate in the work of the corresponding IOC regional subsidiary body, there may be gaps in the geographical coverage of the sampling/observing arrays; third, the scientific investigations carried out under the aegis of the Programme Group are based on national programmes and activities and will not necessarily conform to the geographical coverage chosen for a particular Programme Group. The Technical Secretary then briefly described the boundaries of IOCINCWIO and WESTPAC, recalling that the Assembly did not define the ocean region to be covered by IOCINDIO. However, the IOC Executive Council, at its Seventeenth Session (Paris, 31 January - 9 February 1984), agreed that "the Member States of the region, or active in marine research in the region, should participate in co-operative programmes of the IOC and those being conducted under the auspices of other international organizations in the region of the Red Sea and north-western Indian Ocean and adjacent gulfs". It therefore "urged those Member States not hitherto involved in IOC activities to participate in the IOC regional programmes, instead of creating a new subsidiary body, as, for example, for the Red Sea and Gulf of Aden". It suggested that "the new IOC Programme Group for the Central Indian Ocean (IOCINDIO) should cover the areas of the northern Indian Ocean, adjacent seas and gulfs."

210 The Workshop noted that Thailand, Malaysia, Indonesia and Australia, while being Member States of the Programme Group for WESTPAC, have substantial coastlines bordering the Indian Ocean. So, although the current boundaries of the WESTPAC region actually incorporate coastal parts of the eastern Indian Ocean, national activities of these aforementioned Member States on their western coasts are not likely to contribute substantially to WESTPAC programmes, but would contribute to eventual IOCINDIO programmes. It would be desirable, therefore, that aforementioned Member States become members of IOCINDIO, even if the national marine research in certain fields would not be specifically differentiated into

WESTPAC and IOCINDIO elements. It also noted that, if the WESTPAC region may have eventually to be restricted to western Pacific waters, a limit might have to be drawn across the Straits of Malacca.

The Workshop recognized that there is no obvious southern boundary to the central Indian Ocean, but it recalled that the northern boundary of the region covered by the IOC Programme Group for the Southern Ocean (IOCSOC) is the Antarctic Convergence; although this is a variable oceanic feature, it could, likewise, be recognized as the southern boundary of the central Indian Ocean. 211

The Workshop stressed the close connection between the eastern and western Indian Ocean, and welcomed the suggestion of the Chairman of IOC, at the celebration of the 25th Anniversary of the IOC, to "consolidate the Commission's regional activities, possibly by the progressive merging of certain Programme Groups into Sub-Commissions covering major ocean regions (for example, merging in a few years from now the Programme Groups for IOCINCWIO and IOCINDIO into a Sub-Commission covering the Indian Ocean as a whole), so as better to study the natural phenomena and large-scale oceanographic processes of these major ocean regions". 212

6.3 RELATION WITH IOC PROGRAMME GROUPS FOR CINCWIO AND WESTPAC

The IOC Assembly, in creating the Programme Group for the Central Indian Ocean, was "... aware of the importance of relating the major ocean processes in this part of the Indian Ocean with those in the western part, covered by the Co-operative Investigation in the North and Central Western Indian Ocean (IOCINCWIO) and with the Programme Group for the Western Pacific (WESTPAC). 213

The Workshop noted that it had stressed such co-operation throughout its debates and particularly recommended co-operation on such phenomena as the influence of the Somali upwelling on the Arabian Sea, the Gulf of Aden and the Red Sea, in the western Indian Ocean, and the transport of Pacific water into the Indian Ocean, on the eastern side. 214

6.4 CO-OPERATION WITH OTHER RELEVANT ORGANIZATIONS IN THE INDIAN OCEAN REGION

The Secretary of IOC informed the Workshop of IOC's role in the context of the ICSPRO Agreement, in facilitating co-operation amongst the organizations members of ICSPRO (UN, Unesco, FAO, WMO, IMO) in the marine sciences and related fields. He gave several examples: the IOC-WMO IGOSS; the IOC-FAO OSLR; the IOC-UN(OETB) OSNLR; and the FAO-IOC-UN(OETB) ASFIS; all of which had been mentioned during the preceding discussions. This co-operation also extends to the appropriate regional subsidiary bodies of these organizations; the FAO's Indian Ocean Fisheries Commission (IOFC) is a case in point. The IOC also co-operates as appropriate, with other UN organizations and programmes (e.g., UNEP, ESCAP) and with non-UN regional bodies, notably the Regional Organization for the Protection of the Marine Environment (ROPME) (Kuwait Action Plan Region), the Programme on the Environment of 215 the Red Sea and Gulf of Aden (PERGSA) (of ALECSO) and the Co-ordinating Body for the Seas of East Asia (COBSEA) (South East Asia).

216 The Representative of ROPME, Dr. Manaf Behbehani, informed the Workshop that, since its establishment in 1982, ROPME has adopted an ambitious scientific programme for marine monitoring and research of the Kuwait Action Plan Region. It plans, sponsors and co-ordinates the various programmes that are carried out by scientists and researchers in various national institutions. The Eight Contracting States of ROPME (Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates), in a co-ordinated Programme for Monitoring, have agreed to participate in Pollution and Marine Research. The Programme is known as the "18-month Marine Pollution Monitoring and Research Programme", and includes measurements of oil and non-oil pollutants, oceanographic and meteorological parameters, as well as ecological surveys. Several other important programmes, such as ecological surveys, assessment of mercury levels in edible fish and sediments, assessment of dust fall-out and its effectiveness in sinking oil from the surface of sea water; workshops and symposia, are normally executed by national institutions but, for certain programmes, ROPME relies on the experience and expertise of several UN agencies and international organizations such as UNEP, IAEA, IOC, Unesco and IUCN.

217 The Representative of ROPME stated that it is necessary to identify some specific projects of a global nature on which co-operation between IOC and the Regional Organization could be based. This should be in addition to the regional programmes for which bilateral agreements between IOC and the concerned regional organizations could be reached.

218 The Representative of UNEP, Mr. M. Yeroulanos, presented an overview of UNEP-sponsored co-operative programmes on the protection of the marine and coastal environment in the wider Indian Ocean region, including the monitoring and combatting of marine pollution. Besides global programmes like the Global Environmental Monitoring System (GEMS), UNEP co-ordinates the implementation of the Action Plans of the Regional Seas Programme, which include environmental assessment, environmental management, legal, institutional, financial and supporting measures. There are five Action Plans operating or being developed in the Indian Ocean region (Eastern Africa, Red Sea and Gulf of Aden, Kuwait Action Plan, South Asian Seas and East Asian Seas regions). UNEP intends to continue to enhance these co-operative activities and to encourage interregional co-operation on this basis rather than launching new activities in the wider Indian Ocean area.

219 The Workshop welcomed these expressions of goodwill to co-operate in the context of the Indian Ocean region and called on the IOC to promote such co-operation particularly in the framework of the Programme Group for the Central Indian Ocean.

7. ADOPTION OF THE SUMMARY REPORT

The Workshop considered the draft Summary Report. It agreed that it was satisfactory but required some improvement of style, layout and general editing. It invited the Secretary of IOC to undertake such editing in consultation with the Chairman, Vice-Chairmen and Rapporteur of the Workshop. With that proviso, the Workshop adopted the draft Summary Report. 220

It also agreed that it would be useful if the full manuscripts of the scientific lectures given during the Workshop could be published in a Supplement to the Workshop Report. 221

8. CLOSURE OF THE WORKSHOP

The Chairman thanked the participants for their collaboration throughout the Workshop. He then called on the Chairman of the National Aquatic Resources Agency (NARA), Dr. Hiran Jayawardene, to make a closing statement. 222

Dr. Jayawardene expressed his pleasure at having been able to host this Workshop. He pointed out that the region was only rather recently coming to grips with marine science, marine technology, and marine services and the regional co-operation they require. These developments are especially beneficial to Sri Lanka which is taking its first steps to build up its capabilities in marine science and technology. He regretted not having been able to attend full time, but expressed his appreciation of the success of the Workshop and its usefulness in laying the ground for deliberations planned for the following week in the First Conference on Economic, Scientific and Technical Co-operation in the Indian Ocean in the Field of Marine Affairs in the Context of the New Ocean Regime. Dr. Jayawardene said it had been a privilege for Sri Lanka to offer the services of Prof. Sena de Silva, Professor of Zoology at Ruhuna University in Sri Lanka, as Chairman of the Workshop, particularly since it would contribute to broadening the University's contacts with other scientists from the region and elsewhere. 223

The Secretary of IOC responded. He said it was a very pleasant duty to thank Dr. Jayawardene and the Government of Sri Lanka and to express the appreciation of Unesco and the IOC for their great efforts to ensure the success of the Workshop. He also paid tribute to them for their efforts to develop national capabilities in the marine sciences, particularly NARA. He believed this would facilitate the achievement of national goals. He affirmed the IOC's and Unesco's willingness to assist such efforts. 224

The Secretary also thanked the experts for their collaboration in preparing and delivering papers, even at short notice, and in assisting in the preparation of the Report. The proposals for co-operative research projects were, he noted, at different levels of development, but suggested that they could be further developed before being submitted to the First Session of 225 the Programme Group for the Central Indian Ocean, to be held in the second half of 1986 in Pakistan. The Secretary particularly thanked the Chairman, the Vice-Chairmen and the Rapporteur of the Workshop and the Discussion Leaders for their collaboration.

226 The Representative of Unesco added that the Workshop will be a landmark of marine science co-operation in the Indian Ocean. Hitherto, regional co-operation has, he believed, been too fragmented (e.g., the Red Sea, the Gulf, the Bay of Bengal). This Workshop has brought these together. He also thanked the Government of Sri Lanka for their hospitality.

227 The Representative of ROPME, on behalf of the participants, thanked the Chairman and the other officers for their excellent conduct of the Workshop.

228 The Rapporteur, Prof. A.R. Bayoumi, reminded the participants that a number of persons had been working very hard and late in the Secretariat for the Workshop and gave a vote of thanks to them on behalf of the Workshop participants.

229 The Chairman closed the Workshop at 1930 on 12 July, 1985.

ANNEX I

AGENDA

1. OPENING

2. ADMINISTRATIVE ARRANGEMENTS

    2.1 Designation of the Chairman, Vice-Chairman and Rapporteur of the Workshop
    2.2 Consideration of the Agenda
    2.3 Conduct of the Workshop, Timetable and Documentation

3. MARINE SCIENTIFIC KNOWLEDGE OF THE REGION AND FUTURE CO-OPERATION

    3.1 Ocean Dynamics and Coastal Processes
    3.2 Ocean Processes and Climate
    3.3 Ocean Observing and Monitoring Systems
    3.4 Ocean Science and Living Resources
    3.5 Ocean Science and Non-Living Resources
    3.6 Marine Pollution Research and Monitoring

4. OCEAN SERVICE REQUIREMENTS FOR FUTURE SCIENTIFIC CO-OPERATION

    4.1 International Oceanographic Data Exchange (IODE) and Marine Information Management (MIM)

5. TRAINING, EDUCATION AND MUTUAL ASSISTANCE (TEMA) IN SUPPORT OF PROPOSED SCIENTIFIC RESEARCH PROJECTS

6. BASIS FOR THE FUNCTIONS OF THE PROGRAMME GROUP

    6.1 Proposals for the Terms of Reference
    6.2 Geographic Limits
    6.3 Relation with IOC Programme Groups for IOCINCWIO and WESTPAC
    6.4 Co-ordination with Other Relevant Organizations Active in the Indian Ocean Region

7. ADOPTION OF THE SUMMARY REPORT

8. CLOSURE

ANNEX II

ABSTRACTS OF SCIENTIFIC PRESENTATIONS

PHYSICAL OCEANOGRAPHY OF THE NORTHERN INDIAN OCEAN - A PERSPECTIVE

V.V.R. Varadachari (1)

The northern Indian Ocean, including the Bay of Bengal, the Arabian Sea and the adjacent gulfs, is unique in respect of its physical oceanography and meteorology because of the monsoons. Nowhere else does the ocean undergo such regular, widespread and large-scale seasonal changes in wind forcing and consequent changes in the characteristics of the ocean, especially the circulation. The uniqueness of the northern Indian Ocean and the monsoons led to several international expeditions such as IIOE, ISMEX, MONEX etc., which provided basic data on the oceanography and meteorology of the area. In spite of all these expeditions, our knowledge of the area is still quite meagre.

In order to understand the interannual variability of the monsoons and the mechanisms which determine their variability and their predictability, several components have been identified in the TOGA (Tropical Ocean and Global Atmosphere) and WOCE (World Ocean Circulation Experiment) programme defined by CCCO (the Joint SCOR-IOC Committee on Climatic Changes and the Ocean), for the northern Indian Ocean. Some of the important elements of the programmes are the seasonal cycles of the Somali current system and the equatorial current system, the Arabian Sea surface temperature variations, cross-equatorial fluxes, the surface-layer dynamics, the exchange of energy between the ocean and the atmosphere etc. The sea-level variations, the dynamics of eddies and the transport processes, the vertical and horizontal mixing, the temperature and salinity distribution and the upwelling dynamics of the area are also of significance in our understanding of the interannual variability of the monsoons. The monsoon-dependent ocean circulation and other physical characteristics of the waters of the area, have important impact on most of the other characteristics such as biological productivity, distribution of nutrients, etc.

In addition to the climatic variability of the area, studies on problems such as the genesis of cyclones in the Bay of Bengal, storm surges on the east coast of India, etc., will be of great interest and importance.

In this paper, a review of the state of the art of the problems and the investigations which need regional co-operation, along with the future directions in research, is presented.

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CIRCULATION AND PHYSICAL PROCESSES IN THE ARABIAN SEA AND RELATED PHENOMENA AND PROBLEMS

G.S. Quraishee (1)

This paper considers the relationship between monsoon intensity and four processes or parameters occurring or observed in the Arabian Sea or elsewhere: (i) Geopotential differences: the atmospheric forcing of the ocean during the south-west monsoon has been noted from the wind stress during summer months, when positive stress with strong gradients almost covers the entire northern Arabian Sea; the early indication of the intensification of geopotential differences across the equator appears to have some relationship with the development of monsoon intensity; (ii) Southern oscillations which are large-scale exchanges of atmospheric mass between the eastern and western hemispheres, a see-saw of high pressure in the South Pacific and low pressure in the Indian Ocean, with a cycle of two to six years and correlated with El Nino phenomenon; there is therefore a possibility of correlation between monsoon intensity and the southern oscillations; (iii) Thermal structure of the Arabian Sea: also appears to have a reasonable correlation; (iv) Eddy circulation, which has also been observed, from satellite imagery, to contain warm- and cold-core eddies, and which appears to intensify and, in some areas, persist in the south-west monsoon (May-September); thus, the information about the thermal structure in the eddy fields can also be a useful parameter for prediction of monsoon intensity; (v) Productivity: the whole eddy field is rich in nutrients and dissolved oxygen, which would obviously be expected to increase the local biological productivity, but more detailed studies are required to correlate the intensity of eddy with productivity.

It is possible to predict monsoon intensity from a few weeks to months, and even several years, ahead based on various physical oceanographic parameters and processes resulting from ocean and atmosphere interaction. However, detailed and systematic studies are required to understand the scientific phenomena and refine the forecast.

REVIEW OF PHYSICAL OCEANOGRAPHIC CHARACTERISTICS OF THE KUWAIT ACTION PLAN REGION

T.S. Murty (2) AND M. I. El-Sabh (3)

The physical oceanographic properties in the Inner Gulf of the Kuwait Action Plan Region are reviewed. The meteorological systems that affect the area are considered and special attention is paid to the so-called "Shamal" phenomenon. Significant positive and negative

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storm surges can occur in the Gulf. Water balance is maintained by flow through the Strait of Hormuz, with surface inflow and deep outflow, resulting in a flushing time of a few years. Tidal height patterns and residual currents are also discussed in detail.

AN EXAMINATION OF THE FACTORS THAT INFLUENCE THE MONTHLY-MEAN SEA LEVEL ALONG THE COAST OF INDIA

S.R. Shetye (1)

Available data on monthly mean sea level at eight locations - Veraval, Bombay, Marmagao and Cochin on the west coast, and Nagappatinam, Madras, Vishakhapatnam and Calcutta on the east coast of India - have been used to determine the annual cycle of the sea level. Three other sets of data - atmospheric pressure, ship-drift estimates and rainfall - have been utilized to examine the factors that control the observed variations in the sea level. The main conclusions are as follows: (i) In general, the effect of the atmospheric pressure variation on the monthly mean sea level along the coast is significant; the amplitude of the effect is dependent on location and varies between 4 and 20 cm. (ii) The sea level at Calcutta shows no influence of the large-scale coastal circulation. Off Bombay, the monthly mean coastal currents are weak and do not show significant correlation with the sea level. (iii) At Veraval, Marmagao, Cochin, Nagappatinam, Madras and Vishakhapatnam, the sea level, corrected for atmospheric pressure effects, shows good correlation with the longshore component of the coastal current. The sea-level records at these locations would be a good tool for the long-term monitoring of the surface geostrophic currents along the coast.

STORM SURGES IN THE NORTHERN INDIAN OCEAN INCLUDING THE BAY OF BENGAL AND THE ARABIAN SEA

T.S. Murty (2)

There are two large marginal seas extending northward from the Indian Ocean: the Bay of Bengal and the Arabian Sea. Coastal floods associated with storm surges - the changes in water level generated by storms passing over the sea - constitute the world's foremost natural hazard, surpassing even earthquakes for loss of life and property damage. Nowhere are these losses more serious than in the Bay of Bengal. These surges are caused by tropical cyclones which develop in the southeast part of the Bay or in the Andaman Sea at certain times of the year. The cyclones move along tracks which frequently cross the continental shelves bordering the Bay. A storm surge is generated

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partly by the resulting variations in atmospheric pressure, but the main contribution is produced by the winds, often of exceptional strength, acting over shallow water.

Storm surges are less frequent in Sri Lanka than in Bangladesh, India and Burma. There is no record of a major surge on the Bay of Bengal coast of Thailand. Storm surges are atmospherically forced oscillations of the water level in a coastal or inland water body, in the period range of a few minutes to a few days. By this definition, storm surges are quite distinct from wind waves and swell which have periods of the order of a few to several seconds. Storm surges belong to the same class of waves as tides and tsunamis; that is, long gravity waves. However, tides and tsunamis occur on the oceanic scale whereas storm surges are essentially a shallow water phenomenon.

The Bay of Bengal is a breeding ground for tropical cyclones, the yearly average from 1890 to 1969 being 13. Tropical cyclones capable of generating surges usually occur during the pre-monsoon months (April to May) or the post-monsoon months (September to December), but rarely during the monsoon season. In Burma, storms occur mainly during the pre-monsoon months and affect the Arakan coast.

In the northern reaches of the Bay of Bengal and in the Andaman Sea, the tidal range is comparable to the probable surge amplitudes. The relative timing of high tide and peak surge then becomes very important. The apparent importance of the non-linear effects suggests that dynamical tide-surge interaction must also play a part in the Bay of Bengal. The tide range decreases to the south, so that along much of the east coast of India the tides are small.

The eastern part of the Arabian Sea is one of the tropical cyclone genesis areas on the globe. Most of the tropical cyclones in the Arabian Sea are locally generated. Occasionally, tropical cyclones from the Bay of Bengal traverse the peninsular part of India and get re-intensified over the Arabian Sea. Some cyclones recurve and make a landfall on the west coast of India or on the coast of Pakistan, whereas others travel toward west-northwest and strike the south coast of the Arabian Peninsula.

The frequency of occurrence of storms and storm surges in the Arabian Sea is much less than in the Bay of Bengal. However, the frequency appears to have increased in the last few years. On the Arabian Sea coastlines, the combined effects of storm surges and wind waves have generated water levels in excess of 5 m. If we take into account the high tidal range in the Arabian Sea (8 m at Bombay and 11 m at Cambay), the total water level due to the combined action of storm surges, tides and wind waves could reach 10 to 12 m under extreme conditions.

FISHERY RESOURCES IN THE NORTH ARABIAN SEA AND ADJACENT WATERS

Siebren C. Venema (1)

The Arabian Sea has drawn the attention of oceanographers and marine biologists because of its unique oceanographic phenomena. The reported upwellings and related high primary production off southwest Arabia, Somalia and the Malabar coast of India, have led to high expectation in terms of harvestable fish resources.

Schaefer estimated that the potential yield of the resources off southern Arabia, the Gulf of Aden and Somalia would be of the same order as that of the anchovy fisheries in Peru; viz., around 10 million tonnes.

Subrahmanyan estimated the potential of pelagic fish off the west coast of India at 1 119 000 tonnes based on a comparison with the North Sea, while Shomura put it at 500 000 tonnes. He estimated a potential of demersal fish of 1 430 000 tonnes for India and Pakistan, and an additional 800-850 thousand tonnes for Somalia, the People's Democratic Republic of Yemen and Oman. The total pelagic and demersal production for the Arabian Sea was put at around 4 million tonnes based on Cushing's calculations. The above estimates were all very rough and can now be replaced by better ones for practically the entire area.

The rapid developments in stock assessment by acoustic methods, in particular the echo integrator in the late sixties, made it possible to survey large areas in a relatively short time span with one large vessel. A UNDP/FAO project aiming at assessing the resources off southwest India was subcontracted to the Institute of Marine Research in Bergen, Norway, and the R.V. RASTRELLIGER, built in Norway, became the flagship of the UNDP/FAO fleet of research vessels. FAO, through the Indian Ocean Programme, later entered into a trust fund agreement with NORAD for the construction and operation of the R.V. DR. FRIDTJOF NANSEN, an improved version of the RASTRELLIGER, and equipped with all the then available acoustic instruments for resource surveys. A plan for a two-year survey of the waters from Pakistan to northern Kenya was executed in 1975 and 1976, with an extension under a bilateral agreement for the first six months of 1977 in Pakistan. The survey was very successful. The existence of a large biomass of fish was confirmed; however, the bulk of this biomass consisted of mesopelagic fish, a resource suitable for the production of fishmeal, the economic feasibility of the harvesting of which is not yet known.

In 1979, the R.V. DR. FRIDTJOF NANSEN returned to the Gulfs of Oman and Aden to study further the resources of mesopelagic fish, and in 1981 a similar survey was made followed by very short surveys of the waters off Djibouti and the Gulf of Suez. In 1983, the DR. FRIDTJOF NANSEN, funded by NORAD and a global UNDP/FAO project, returned once again to the Arabian Sea for a longer-term programme. The harvestability of mesopelagic fish was tested with success in the Gulf of Oman in January/February. The other resources of Oman were assessed in March. After a short survey in the Maldives in August, the first of its kind in that country, the vessel will proceed to Pakistan and Iran to start another series of surveys in that area, followed by others off Oman and in the Gulf of Aden.

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The estimates of standing biomass, and the potential yields derived therefrom, obtained through all these surveys and other assessments, including a few examples of classical stock assessments, will be compared with actual landings, as reported in the FAO Statistical Yearbook (FAO, 1983) to assess sustainable levels of exploitation and the possibilities for development. Attention will also be paid to the relationship between climatic variability in oceanographic phenomena and fluctuations in the abundance of living resources, in particular tuna.

This review includes the Arabian Sea from the Maldives to Somalia, the Gulfs between Iran and the Arabian peninsula, the Gulf of Aden and, to a limited extent, the Red Sea. The fish resources are discussed by major surveys or areas, while tunas, crustaceans and cephalopods are dealt with separately. Mesopelagic fish resources have been described by Gjosaeter (1984).

REVIEW OF THE ECOLOGICAL CHARACTERISTICS OF THE KUWAIT ACTION PLAN (KAP) SEA REGION

M. Behbehani (1)

Despite many surveys and ecological studies in several areas of the ROPME sea area, the over-all ecological features of this regional water are not well defined and understood. The information available indicates that the fauna and flora of the ROPME sea area north of Hormuz are that of a shallow enclosed basin with only a few oceanic representatives, while the biota of the Gulf of Oman and the Arabian Sea have more affinity to Indian Ocean species.

The sea area contains a high number of marine plant and animal species esecially in such habitats as mud flats and some coral reefs. On the other hand, sandy beaches, which occupy the majority of the coastal areas, are relatively low in species diversity compared to similar habitats elsewhere. The open-sea environment has varied species composition depending on location.

One main ecological feature of ROPME sea area is high primary and secondary productivity in its northern and southern sections. In the north, this is due to the rich nutrient input from Shatt Al-Arab, while in the south, the high productivity is due to the upwelling off the southern coast of Oman.

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MARINE LIVING RESOURCES OF THE RED SEA

A.R. Bayoumi (1)

Physical and biological oceanographers have stressed the uniqueness of the enclosed, highly saline Red Sea. Its special place is accentuated by its predominantly north-south geographic orientation.

The fauna and flora of the Gulf of Suez, the Gulf of Aqaba and the Red Sea consist almost entirely of members of the tropical Indo- Pacific assemblage, and many of the species range across the Indian Ocean into the central tropical Pacific.

The flora of the Red Sea, comprising about 400 species of seaweeds, 10 sea grasses, 50 cyanophytes and two species of mangrove trees, has an Indo-Pacific origin enriched by some species of algae from the Mediterranean Sea. Generally speaking, the distribution of species in the Red Sea shows great variability in the vegetation of the Arabian, African, Gulf of Suez and the Gulf of Aqaba coasts.

Pelagic and benthic communities of the Red Sea are intimately linked with its hydrography which differs from normal oceanic conditions. This abnormality is largely due to the partial isolation of the Red Sea from the open ocean, the prevailing wind system and excessive evaporation.

The present paper is a review and updating of the available information and studies on the living resources of the Red Sea. It also reviews the role of variable environmental conditions, both natural and man-made, affecting behaviour of some individual species.

The Red Sea fauna and flora are good examples for the study of migration, endemism and distribution of marine organisms.

The paper also suggests the most important studies and research programmes needed to be conducted over long periods of time.

COMMUNITY STRUCTURE AND BIOMASS OF THE RED SEA AND RELATED MARINE BIOLOGY PROBLEMS OF THE RED SEA AND THE GULF OF ADEN

Hjalmar Thiel and Horst Weikert (2)

Nutrient levels are mainly governed by production and degradation of organic matter. Productivity and standing stocks of nekton, plankton and benthos are low in most parts of the Red Sea basin and the Gulf of Aden water inflow and are, to some extent, comparable to other oligotrophic regions. However, in the bathyal, the biomass ranges one order of magnitude lower than in the Sargasso Sea and the North Pacific gyre.

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Related to the inflow of Indian Ocean water through the Straits of Bab el Mandeb, especially during winter, productivity, biomass and diversity are obviously higher in the southern Red Sea, showing a distinct decline between 17° and 19° N, but with a gradual decrease towards the north. The waters in the northern Gulfs deviate from the Red Sea waters to some extent, while the Gulf of Aden is strongly influenced by the Indian Ocean, characterized by cold deep water, intense seasonal upwelling, and resultant higher productivity.

Plankton and benthos reef biocoenoses differ considerably from the open-ocean regions indicating some energy exchange between the inshore and offshore regimes.

The Red Sea is briefly characterized and those areas of interest in which research should be stimulated are indicated. Our studies in the Red Sea are aimed at potential risk assessment for mining of metalliferous sediments from the Atlantis II Deep. Therefore attention is concentrated on the central Red Sea around 21°N.

Hydrographically, the area belongs to a transition zone between the northern part, with surface currents flowing southwards throughout the year, and the southern part, with surface currents setting north in winter and south in summer. These regional patterns are related to the monsoon winds.

Surface salinity and temperature in the Red Sea proper range from 36.5 to 41 and from 21.6° to 31°C, respectively. The unique deep water body has a temperature of 21.6°C and a salinity up to 42. Chemically and biologically, the water column may be divided into distinct vertical zones: the epipelagial, covering the upper 100m; the mesopelagial, in the depths between 100 and about 750m; the bathypelagial, down to the seabed.

Oxygen concentrations in the surface layer are up to saturation and related to the phytoplankton assimilation. A distinct minimum zone is found between 300 and 400m (depth). A subsequent increase to about 2ml/l is observed throughout the deeper parts.

OCEANOGRAPHIC CONDITIONS, PELAGIC PRODUCTIVITY AND BIO-RESOURCES IN THE GULF OF ADEN

J. Stirn, R. Edwards, J. Piechura, M. Ghaddaf, F. Mutlaq, O. Sabih, M. Savich, S. Shaher and Z. Zubairi (1)

Although the basic oceanographic conditions and processes in the Gulf of Aden and adjacent parts of the Arabian Sea (2) in particular the upwelling phenomena and consequently high pelagic

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(1) Marine Science and Resources Research Centre and Unesco Field Project 703/PDY/40 Aden, P.D.R. Yemen

(2) Somali-current area and the shelf of Socotra

bioproductivity, are quite well known since the IIOE (1) and repeatedly reported in the scientific literature, the actual oceanographic information is rather fragmentary. This contribution provides a review of existing relevant knowledge, as related also to exploitable bioresources and enriched by the results, obtained by recently introduced systematic investigations in P.D.R. Yemen.

All oceanographic processes in this area are subject to expressed temporal - spatial fluctuations and are of great variability. Therefore, their understanding requires systematic long-term and high-frequency oceanographic investigations as well as continuous weather observations, covering the whole area.

Adequate knowledge of the oceanographic conditions and of the dynamics of pelagic bioproductivity present, for this area, not only a target of basic science, but also the very source for the understanding of variable sizes and distributions of exploitable sea-food resources.

Considering these resources, the current, quite reliable assessments (2) show the remarkable sizes of unexploited stocks. In the first place, the perspectives for further increased exploitation apply to pelagic populations. In addition, the demersal stocks show considerable potential, provided the fisheries can be brought under control with rational management.

Because of the fluctuations of the oceanic environment and pelagic productivity and, in particular, the temporary appearances of anoxic conditions in shallow waters, due to upwelling, the variability and migrations of fish stocks are remarkable. Considering this and the the very fragile, yet poorly known biological interrelationships within tropical fish communities, it becomes rather obvious that systematic fishery biological research, connected with inter-disciplinary oceanographic investigations, present the very basis for an increased and rational exploitation of this region's marine bioresources.

As mentioned above, most of the needed investigations must, *a priori*, cover the whole area of the Gulf of Aden and adjacent parts of the Arabian Sea, since they present a functional unit, at least as far as oceanographic processes are concerned. However, the area is extensive and the seas during the summer monsoon are heavy.

Therefore, the sea-going research requires a sizeable (3) and well equipped research vessel, operating continuously year around with

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(1) International Indian Ocean Expedition 1959-1965
(2) Based mainly on the results of FAO/Norway surveys (1975-76, 1984), performed with R.V. DR. FRIDTJOF NANSEN and recent investigations in P.D.R. Yemen with R.V. IBIN MAGID (from 1983 on).
(3) At least a 600-BRT vessel

an interdisciplinary scientific team aboard. Probably, no single country bordering this area (1) can support alone the capital and running costs, and even if so this would mean an uneconomic duplication of efforts. Therefore, it is proposed herein to set up a relevant regionally operating organisation, shared by all bordering (1) countries and supported by a UN interagency corporation (2) . A tentative scientific programme of interdisciplinary oceanographic and fisheries investigations of this area is proposed as well.

STATUS OF CRITICAL MARINE HABITATS IN THE INDIAN OCEAN

R. Ormond (3)

Critical marine habitats are those that are critical to maintaining the renewable resources of a region, either because they are much more productive than surrounding waters, or because they are the critical breeding or nursery grounds of species which form part of that resource or are of special interest. In the Indian Ocean, such critical habitats include coral reefs, mangrove stands, seagrass beds, mud flats and islands and coastal sites which are the breeding grounds of turtles and seabirds. This paper reviews the distribution and status of these critical habitats throughout the Indian Ocean Region.

Coral reefs are especially well developed in the Red Sea, on the islands of the Indian Ocean and around the smaller islands of southeast Asia. However, perhaps 20 percent of reefs within the region have been damaged or destroyed, mainly as a result of sedimentation and of mining and other forms of direct destruction. Extensive mangrove forest occurs especially in northern India, in Bangladesh and in southeast Asia, but an estimated 50 percent of mangroves have been destroyed in the past 10-15 years, through felling for fuel, land use or chipboard production, despite their essential role in supporting fisheries for shrimp and many fish species. About fifteen species of seagrass form extensive communities in shallow sandy areas throughout the region and are important as nursery areas for fish and shrimp, but increasingly these are being damaged by dredging, coastal infill, trawling and sedimentation; increasing disturbance and exploitation of small islands throughout the region has been a major factor in the precipitous decline of many populations of all species of marine turtle and of some species of seabird.

Loss of critical habitats has resulted in a significant decrease in the potential fishery resources of the area, direct habitat destruction and over-exploitation of fish stocks and other species are the major factors causing deterioration of the marine environment; action is urgently needed throughout many parts of the region to improve the protection and management of critical habitat areas and the resources which they represent. The needs for full and reliable data on the distribution of critical habitats and for effective coastal zone management planning are emphasized and discussed.

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(1) Djibouti, Somalia and P.D.R. Yemen; in addition, A.R. Yemen and Oman could make good use of results.

(2) UNDP/FAO/UNESCO-IOC/UNEP

(3) TMRU Biology Department, York University, England

RESEARCH NEEDS FOR THE CORAL REEF ECOSYSTEMS OF THE CENTRAL INDIAN OCEAN

M.W.R.N. de Silva (1)

Coral reefs are unique tropical ecosystems that are important to the fisheries and tourist industries and are regarded as breeding and nursery grounds of several marine organisms . In addition, they act as barriers which prevent sea erosion. The potential of several coral reef organisms as producers of medicinally important compounds has received the close attention of scientists in recent years. Unfortunately, these valuable coral reefs have not received the attention nor the respect due to an ecosystem which the scientists consider as one of the most productive of all natural ecosystems on earth. At present, coral reefs are over-exploited, damaged and subjected to destruction without much concern for their future well-being. If this state of affairs continues unchecked, many of the central Indian Ocean's coral reefs without doubt will have a bleak future.

Most of the available information on the coral reefs of the central Indian Ocean pertains to the taxonomy and biogeography of the reef biota. Information on the structure of reef communities and their physiographic zonation is limited to a few reefs in the region.

Major causes of coral reef degradation in the region are coral mining, use of explosives for fishing, sedimentation, tourist pressure and the removal of coral, reef fish and other reef organisms as souvenirs, or for export to the aquarium trade. 'Crown of Thorns' starfish (*Acanthaster planci*) infestations have also caused the destruction of some reef areas. According to the IUCN Coral Reef Newsletter No. 4 of 1982, only a very few countries in the Indian Ocean region have attempted to control the degradation of their coral reefs by the establishment of Coral Reef Parks or Reserves.

The main research needs in the central Indian Ocean and the adjacent regions are:

(i) Further surveying and mapping of coral reef areas.
(ii) Assessing coral reef quality in terms of species diversity, percentage live/dead coral cover and the ecomonic value as indicated by its exploitation for fisheries, tourism and for other purposes.
(iii) Determining the causes and the rates of degradation of coral reefs.
(iv) Carrying out research aimed at providing evidence of the value of coral reefs such as for fisheries and as breeding and nursery grounds.
(v) Determining the Maximum Substainable Yield (MSY) of exploitable coral reef resources.
(vi) The standardization of coral reef research methods to make results comparable.
(vii) A concerted effort at rationally managing and conserving coral reefs.

(1) National Aquatic Resources Agency, Crow Island, Mattakuliya, Colombo, 15, Sri Lanka

Coral reef research in many of the central Indian Ocean countries has remained at a low level of priority because of the following:

(i) Lack of proper understanding by the policy makers of the value and vulnerability of coral reefs.
(ii) Lack of sufficient funds, scientists and expertise to carry out coral reef research.

The development of a central pool of Indian Ocean coral reef research and management expertise in collaboration with other relevant marine disciplines, with the blessings of the governments concerned, could provide the nucleus for much needed co-operative and comparative coral-reef research in the region. Such a central pool of expertise would not only cater for the maximum utilization of the limited number of coral reef scientists in the region, but would also enable

(i) the standardization of research techniques and the training of others.
(ii) the identification of areas for conservation and co-operative research as well as the identification of coral reefs that need to be protected on a regional basis.

There is also a need in the central Indian Ocean and the adjacent region for a coral reef research data collection and dissemination service as well as a regional base for concerted efforts for rationally managing and conserving coral reefs.

RED TIDES IN THE INDO-WEST PACIFIC REGION

Gustaaf Hallegraefe (1)

The most common red-tide organisms in the Indian Ocean, the blue-green alga, *Trichodesmium erythraeum*, and the dinoflagellate, *Noctiluca scintillans*, produce mostly harmless water discolorations. Only in exceptional cases can such plankton blooms cause fish kills in sheltered bays due to the generation of anoxic conditions. The raphidophyte flagellate, *Chattonella marina*, has caused fish kills in India by releasing free fatty acids which destroy the gill tissues of fish. There is evidence that some red tide problems (e.g., *Chattonella*, *Noctiluca*) are aggravated by industrial pollution but other plankton blooms (e.g., *Trichodesmium*) bear no relationship to eutrophication.

Red tides caused by toxic dinoflagellates, which produce potent neurotoxins that can find their way through fish and shellfish to man, are well documented from Europe, North America and Japan. At present, paralytic shellfish poisoning (PSP), diarrhoetic shellfish poisoning (DSP) and ciguatera fish poisoning are virtually unknown from the central Indian Ocean. Admittedly, surveys for the causative dinoflagellate species have been inadequate and ethnic dietary habits (low shellfish consumption) may also play a role. Attention is drawn to the apparent spreading of *Pyrodinium bahamense* var. *compressa* (PSP) through the East Indies (Papua New Guinea, Philippines, Malaysia,

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Indonesia), and <u>Protogonyaulax tamarensis</u> has caused recent PSP fatalities in Thailand and possibly India.

It is recommended that a basic training workshop be conducted for local workers responsible for microscopic plankton taxonomy to enable them to recognize potentially toxic species and their benthic cysts. In addition, public health officials should be made aware of the clinical symptoms of various types of shellfish and fish poisoning to ensure that, if necessary, warnings can be issued promptly and effectively.

AN ENVIRONMENTAL OVERVIEW OF THE INDIAN OCEAN (1)

R. Sen Gupta (2) and S. Z. Qasim (3)

The physical, chemical, biological and geological characteristics are described in a general way.

An analysis of data collected on different environmental parameters by India, the Indian Ocean islands and the East African countries is made, covering (i) the four parameters of oil pollution (oil slicks and other pollutants, floating petroleum residues, dissolved/dispersed petroleum hydrocarbons, and beach tar) and (ii) levels of toxic and non-toxic heavy metals and metalloids in water and marine organisms, with emphasis on mercury, cadmium and lead.

An attempt has been made at assessing the impact of domestic and industrial sewage and effluents, fertilizers and pesticide residues at their present concentrations.

The general conclusion is that the coastal areas of almost all the countries of the Indian Ocean region are either contaminated or are being contaminated and need careful attention.

MINERAL RESOURCES OF THE INDIAN OCEAN AND RELATED SCIENTIFIC RESEARCH

H.N. Siddiquie, A.R. Gujar, N.H. Hashimi
A.B. Valsangkar and B. Nagendra Nath (4)

The sea floor of the Indian Ocean and the continental margins bordering the oceans are covered by a wide variety of terrigenous, biotic and chemical mineral deposits.

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(1) Based on paper entitled "The Indian Ocean - An Environmental Overview" in The Oceans - Realities and Prospects (ed. R.C. Sharma), pp. 7-40, Rajesh Publications, New Delhi, 1985.
(2) National Institute of Oceanography, Dona Paula, 403 004 - Goa, India
(3) Secretary of State, Department of Ocean Development, New Delhi, India
(4) National Institute of Oceanography, Dona Paula, Goa - 403 004, India

Terrigenous heavy mineral placers are known from the beaches of South Africa (ilmenite, rutile, monazite and zircon), Mozambique (ilmenite, zircon, rutile, garnet and monazite), Tanzania (garnet, ilmenite, kyanite, zircon, magnetite and monazite), western India (ilmenite, rutile, zircon, magnetite, garnet and monazite), Sri Lanka (ilmenite, rutile, monazite, zircon and garnet), Malaysia (tin), Burma (monazite and zircon), Indonesia (tin, ilmenite, titaniferous magnetite, monazite and zircon) and western Australia (rutile, ilmenite, zircon, garnet and monazite). The exploration of these deposits offshore has also been carried out and the results have been particularly encouraging off Mozambique, western India, Sri Lanka, Malaysia and western Australia. The humid tropical climate of some of the land areas bordering the Indian Ocean accelerates weathering of the source rocks. This, coupled with the large river run off and wave and current conditions, favours the formation of a variety of placer deposits. The beach and offshore placer deposits of the Indian Ocean may be one of the largest in the world.

The biotic deposits in the Indian Ocean comprise the corals on shallow banks and on the continental shelves and the oozes in the deep sea. The biotic deposits are a low-priced commodity and are likely to be exploited only in coastal areas for local construction, cement and chemicals, where offshore limestone deposits are not available. A minor use of shells and corals is for semi-precious and ornamental purposes. It is unlikely that the deep sea oozes will be exploited in the near future. The deposits of calcareous sands, shells and corals are being exploited on a large scale in India for the manufacture of cement, and exploration in some of the areas has indicated reserves of over a thousand million tons. It is expected that, in many countries, especially the islands whose economy is largely dependent on tourism, restraint would be exercised on the exploitation of these deposits. A study of the deposits would undoubtedly lead to a better understanding of their formation, turnover, regeneration rates and substainable yields and in turn to their better management.

The chemical deposits in the Indian Ocean comprise the phosphorites and the polymetallic nodules. Occurrences of phosphorite deposits in the Indian Ocean are reported both from the continental margins (South Africa and western India) and the seamounts (eastern and western Indian Ocean). The continental margins of South Africa, East Africa, southern Arabia, western India and the Andamans are marked by strong upwelling as also non-depositional environments which are conducive to the formation of phosphorite. The onshore deposits are sufficient to meet the requirements in the near future. The exploitation of the marine deposits would be feasible in certain coastal areas where the cost of imported fetilizers and transport can offset the higher cost of marine mining. The exploitation of the deposits even in the future would provide a significant input to the dominantly agricultural economies of many of the countries in the Indian Ocean.

The polymetallic nodules in the Indian Ocean cover an area of 10-15 million square kilometres and the resources are estimated to be about 0.17 trillion tons. A study of over 900 chemical analyses from 350 stations shows that the deposits in most of the basins are submarginal. The deposits in the central Indian Ocean may only be categorized as paramarginal (Ni + Cu + Co over 2.47 per cent and abundance over 5kg/m). The exploration of submarginal deposits may however lead to the identification of potential areas for later development.

Most of the exploration for minerals, even on the continental margins of the Indian Ocean, has been carried out by the developed countries from outside the region and little work has been carried out by the countries bordering the Indian Ocean. The development of capabilities within the region for exploration of the mineral resources should receive a high priority. The exploration of the mineral resources of the Indian Ocean would not only add to an inventory of the resources in the world oceans but also lead to a greater understanding of the formation of marine mineral deposits.

The analyses of the present capabilites (trained manpower, equipment and vessels) for exploration for marine non-living resources in the region indicates that these are confined to a few countries only. In this context, the programmes for exploration of non-living resources will necessarily have to be phased. The phasing could be

(i) compilation of the basic data for planning
(ii) near-shore exploration
(iii) exploration of the continental shelf and
(iv) exploration of the deep sea.

In countries with limited manpower in marine geosciences, a beginning could be made by associating physical, chemical and biological oceanographers. This would be useful to identify the areas for the exploration for terrigenous deposits (heavy mineral placers), biotic deposits (shells and corals) and chemical deposits. After the initial planning has been carried out, the work could be initiated with limited manpower on smaller vessels (even fishing trawlers) in the nearshore areas and later, with the acquisition of equipment and larger vessels, over the continental shelf and in the deep sea. Indian scientists have developed collaboration programmes with Sri Lanka and Seychelles, and programmes for collaboration with Mauritius are now being drawn up.

GEOLOGICAL-GEOPHYSICAL MAPPING OF THE INDIAN OCEAN

N.N. Turko, G.B. Udintsev, D.I. Zhiv (1)

Several stages can be distinguished in the history of geological-geophysical mapping of the Indian Ocean. Data on bottom relief and sediment distribution were the prime interest at the first stage; then, data on magnetism, gravity, continuous seismic profiling and others were also considered in the mapping.

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Some maps, particularly the 3rd edition of the General Bathymetric Chart of the Oceans (GEBCO), were published as a result of the first stage which lasted from the middle of the 19th to the fourth decade of the 20th century.

After World War II, research was restarted and this is the second stage. New techniques were used, and some expeditions, including investigations during the International Geophysical Year, were organized. As in the first stage, the data were isolated and maps compiled from them were therefore very schematic.

An important new stage in oceanic research covered the period 1960- 1965, corresponding to the International Indian Ocean Expedition (IIOE). More than 20 countries participated in that research. Some important geographic discoveries were made, and thus the main orographic scheme became clear; since then, it has served as the basis for further survey of separate features. The results of the IIOE appeared in the maps of the International Geological-Geophysical Atlas of the Indian Ocean (1975). Tracks plotted on the maps reflected the state of knowledge, which allowed users to distinguish between the real data and their interpretation.

These maps also include the new data obtained after IIOE, when parts of other international projects (Upper Mantle Project and Deep Sea Drilling Project) were carried out in the Indian Ocean. Research on rift zones within the Upper Mantle Project marked the beginning of a new stage which included detailed surveys of prefixed areas (polygons). Such investigations of separate areas by a complex of different methods were carried out in recent years in the Red Sea and Bay of Bengal, on the continental margins of India and Australia, on the Karlsberg, Ninety East, Mascarene, Broken and Kerguelen ridges, in the Central and Wharton basins etc.

As a result, the bathymetric, magnetic, gravity, geological and other charts were compiled for some features and regions, and some tectonic maps - for the whole ocean or large parts of it - were prepared. The GEBCO chart 5th edition (published in 1982) and the International Tectonic Map of the World (presented at the International Geological Congress, Moscow, 1984) show the progress in our knowledge.

The complex structure of the Indian Ocean floor, namely great morphological and geophysical variety along the mid-ocean ridge, active and passive margins, a great number of aseismic ridges, zones of intraplate deformation, etc., requires further study of this Ocean.

The research along geotraverses (i.e., detailed studies of bands of ocean floor from continent to continent, crossing different structures), will be a new step in this direction. At present, such research is carried out in the Atlantic (Angola-Brazil geotraverse). This kind of work allows the three-dimensional pattern of ocean bottom structure to be determined and allows one to see the inter-relations of different features.

DESTRUCTION OF THE TETHYS AND PALAEO-OCEANOGRAPHIC DEVELOPMENT OF THE INDIAN OCEAN

Bilal U. Haq (1)

The floor of the Indian Ocean was carved at the expense of the ancient circum-global Tethys Seaway. The destruction of the eastern limb of the ancestral Tethys and the evolution of the modern Indian Ocean were simultaneous and intimately related. The western and eastern sides of the ancient Tethys were first connected some 175 million years (m.y.) ago when the Central American passage first opened. But the development of the Indian ocean can be said to have begun some 210 m.y. ago with the initial breakup of the Gondwanaland supercontinent. Palaeogeographic events such as the separation of Madagascar from Africa, the rifting between Australia-Antarctica and Africa, and the split between Antarctica and Australia were important thresholds in the development of the Indian Ocean. However, the most important event that led to the development of this new basin and the closure of the Tethys Seaway was the rapid movement of the Indian plate towards Eurasia that began some 80 m.y. ago. The circulatory and climatic patterns during these developments differed significantly from their modern counterparts and were strongly influenced by the continental positions and opening and closing of surface and deep water connections. The patterns of sedimentation were in turn influenced by the changing hydrographic and climatic patterns.

The collision of India with Eurasia, some 50 m.y. ago, sealed the fate of the ancestral Tethys and the eventual closure of the oceanic pathways north and east of the Indian Plate. The Tethys was essentially closed 30 m.y. ago, and the development of the present-day climatic and circulation patterns, and their attendant coastal regimes, drainage, and sedimentary patterns, were initiated by this time.

Here the palaeogeographic events that led to the destruction of the Tethys Seaway and the development of the Indian Ocean, and the oceanographic-climatic evolution of the region, are reviewed. The sources for this review are varied, and based on geophysical, sedimentological and palaeontological evidence from the deep sea, as well as stratigraphic data from the continents surrounding the Indian Ocean.

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THE CRUST BENEATH THE RED SEA - GULF OF ADEN - EAST AFRICAN RIFT SYSTEM: A REVIEW

How Kin Wong, Egon T. Degens & Venugopalan Ittekkot, Hamburg (1)

The Red Sea-Gulf of Aden-East African Rift System is one of the key areas central to a study of the rift-drift process. Within this single system, geodynamic processes ranging from uplift, block-faulting, volcanism, seismic activity, to hydrothermal circulation and seafloor spreading are represented. In the present article, the geological, geophysical , sedimentological and geochemical characteristics of this area are reviewed. Special emphasis is placed on the structure and evolution of the crust, as well as on their implication to continental rifting and plate accretion.

SEDIMENTARY STRUCTURE OF THE NORTHERN RED SEA PREPARATRION OF A 1 : 1 000 000 BATHYMETRIC CHART OF THE NORTHERN RED SEA AND STUDY OF THE MORPHOSTRUCTURAL FRAMEWORK BY CARTOGRAPHIC ANALYSIS

A. Ferragne, R. Griboulard, R. Prud'Homme, J-M. Ratel and M. Vigneaux (2)

Continuous analysis of the northern Red Sea domain has been made for the marine and the continental areas. A 1 : 1 000 000-scale bathymetric chart has been drawn on the basis of relevant GEBCO plotting sheets, correlated with marine charts from the Service Hydrographique de la Marine. The morphology is described in the structural framework of this domain, with a three-dimensional visualization of the seafloor relief. The orientation and deep variations of the axial valley are shown, with the presence of submarine deeps. The main characteristics of the marginal shelf are confirmed both in the morphology and the lithological and sedimentary structure. The evident dissimilitaries between the Gulfs of Suez and Aqaba, because of their genetic differences, are perfectly illustrated. Cartographic analysis, by a filter effect, allows the elaboration of a synthetic morphostructural sketch. The essential part of the ante-opening regional geological structure (structure at 30°N, Zabargad transitional zone, at 20°N Al Nadj fault zone) is revealed; this part controls the evolution of the marine domain. The role of rifting structures, such as transform faults, is confirmed. The Agaba Gulf Fault appears clearly as a sinistral zone. Through the investigation of depth variability by morphostructural analysis, a definition of domains with different morphostructural characteristics can be considered, in connection with regional geological evolution. The main deeps bordering the median axis of the rift are observed to cross transversal structures which are described in this study.

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SUPERFICIAL SEDIMENTS OF NORTHERN RED SEA

M. Kh. El-Sayed (1)

Several geological studies have been made of Recent Red Sea sediments. Most of these studies were restricted to the central part of the Red Sea (21°N) in active zones mostly characterized by metalliferous sediments.

The superficial sediments of the northern Red Sea have received but little attention; however, early investigation in the region some forty years ago described the sediment's origin, texture and mineralogy. These supeficial sediments are calcareous and mostly of organic origin. Aragonite is considered by far the most dominant carbonate mineral in these sediments which are of fine to medium grain and mostly normally to well sorted.

The mineral assemblages (heavy and light) of these sediments depend on the nature of distributive rocks, weathering and post-depositional changes.

Reefal sediments are very common in the nearshore areas of the northern Red Sea. Several investigations have been carried out to identify their types, texture, distribution, minerals and chemical composition. These studies were conducted in Al-Agaba and Al-Ghardaqa.

The deep zones of the northern Red Sea are partially covered by hydrothermal deposits or normal Red Sea sediments. The new discovery of some brine pools in the northern Red Sea offers an excellent opportunity to study these sediments and to define active and non-active zones.

RISING SEA LEVEL AND CHANGING SEDIMENT INFLUXES FROM RIVERS TO THE OCEAN: A REAL AND FUTURE PROBLEM FOR INDIAN OCEAN NATIONS

John D. Milliman (2)

Within the next 100 years, the combined effects of sea-level rise, subsidence and the damming and diverting of major rivers could effect a shoreline regression of more than five kilometres in many deltaic areas bordering the Indian ocean. Oceanographers may have little control in many of the policy decisions regarding the rising sea level or the damming of rivers, but, by documenting the coastal environments, they can at least estimate the potential damage as well as suggest ways in which the impact could be lessened.

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ANNEX IV

LIST OF ACRONYMS

ALECSO	Arab Educational, Cultural and Scientific Organization
ASFA	Aquatic Sciences and Fisheries Abstracts
ASFIS	Aquatic Sciences and Fisheries Information System
CCCO	Joint SCOR-IOC Committee on Climatic Changes and the Ocean
COBSEA	Co-ordinating Body for the Seas of East Asia
COMAR	Coastal Marine Systems
DSP	Diarrhoetic Shellfish Poisoning
EEZ	Exclusive Economic Zone
ESCAP (UN)	Economic and Social Commission for Asia and the Pacific
FAO	Food and Agriculture Organization of the United Nations
GEBCO	General Bathymetric Chart of the Oceans
GEEP	Group of Experts on the Effects of Pollutants
GEMS	Global Environmental Monitoring System
GEMSI (IOC)	GIPME Group on Experts on Methods, Standards and Intercalibration
GIPME (IOC)	Global Investigation of Pollution in the Marine Environment; Working Committee for GIPME
GTS	Global Telecommunication System
IAEA	International Atomic Energy Agency
IBCWIO	International Bathymetric Chart of the Western Indian Ocean
ICSPRO (UN-FAO-Unesco-WMO-IMO)	Inter-secretariat Committee on Scientific Programmes Relating to Oceanography
ICSU	International Council of Scientific Unions
IFREMER	Institut Francais de Recherche pour l'Exploitation de la Mer

IGOSS (IOC-WMO)	Integrated Global Ocean Services System
IIOE	International Indian Ocean Expedition
IMO	International Maritime Organization
IOBC	Indian Ocean Biological Centre
IOC	Intergovernmental Oceanographic Commission
IOCARIBE	IOC Sub-Commission for the Caribbean and Adjacent Regions
IOCINCWIO	IOC Programme Group for the Co-operative Investigation in the North and Central Western Indian Ocean
IOCINDIO	IOC Programme Group for the Central Indian Ocean
IOCSOC	IOC Programme Group for the Southern Ocean
IODE (IOC)	International Oceanographic Data Exchange
IOFC (FAO)	Indian Ocean Fisheries Commission
ISMEX	Indo-Soviet Monsoon Experiment
IUCN	International Union for Conservation of Nature and Natural Resources
KISR	Kuwait Institute for Scientific Research
MARPOLMON (IOC)	Marine Pollution Monitoring Programme
MIM	Marine Information Management
MONEX	Monsoon Experiment
MSCT	Marine Science Contents Tables
MSY	Maximum Sustainable Yield
NARA	National Aquatic Resources Agency
NIO (India, Pakistan)	National Institute of Oceanography
NODC	National Oceanographic Data Centre
NORAD (Norway)	Norwegian Agency for International Development
OETB (UN)	Ocean Economics and Technology Branch
ODP	Ocean Drilling Programme
OOSDP	Ocean Observing System Development Programme
OSLR (IOC-FAO)	Ocean Science in Relation to Living Resources

OSNLR (IOC-UN(OETB))	Ocean Science in Relation to Non-Living Resources
PERGSA	Programme on the Environment of the Red Sea and Gulf of Aden
PSMSL	Permanent Service for Mean Sea-Level
PSP	Paralytic Shellfish Poisoning
ROPME	Regional Organization for the Protection of the Marine Environment
SCOR (ICSU)	Scientific Committee on Oceanic Research
SST	Sea Surface Temperature
TEMA (IOC)	Training, Education and Mutual Assistance in the Marine Sciences
TOGA	Tropical Ocean and Global Atmosphere
UN	United Nations
UNCLOS	United Nations Conference (or Convention) on the Law of the Sea
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCP (WMO)	World Climate Programme
WCRP (ICSU-WMO)	World Climate Research Programme
WCRP-O	The Oceanographic Component of the WCRP
WDC	World Data Centre
WESTPAC	IOC Programme Group for the Western Pacific
WHO	World Health Organization
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW (WMO)	World Weather Watch
XBT	Expendable Bathythermograph

No.	Title	Publishing Body	Languages
32 Suppl.	Papers submitted to the UNU/IOC/Unesco Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the Context of the New Ocean Regime Paris, 27 September-1 October 1982	IOC, Unesco Place de Fontenoy Paris, France	English
33	Workshop on the IREP Component of the IOC Programme on Ocean Science in Relation to Living Resources (OSLR) Halifax, 26-30 September 1983	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
34	IOC Workshop on Regional Co-operation in Marine Science in the Central Eastern Atlantic (Western Africa) Tenerife, 12-17 December 1983	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish
35	CCOP/SOPAC-IOC-UNU Workshop on Basic Geo-scientific Marine Research Required for Assessment of Minerals and Hydrocarbons in the South Pacific Suva, Fiji, 3-7 October 1983	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
36	IOC/FAO Workshop on the Improved Uses of Research Vessels Lisbon, 28 May - 2 June 1984	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
36 Suppl.	Papers submitted to the IOC-FAO Workshop on Improved Uses of Research Vessels Lisbon, 28 May-2 June 1984	IOC, Unesco Place de Fontenoy 75700, Paris, France	English
37	IOC/Unesco Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs Colombo, 8-13 July 1985	IOC, Unesco Place de Fontenoy 75700, Paris France	English