NETHERLANDS INDIAN OCEAN PROGRAMME

Scientific Programme Plan

The Hague, November 1991

Contents

4

1 9 9 0 - 1 9 9 5

Executive Summary

This book describes the Netherlands Indian Ocean Programme (1990-1995). The Programme is organised by The Netherlands Marine Research Foundation (SOZ) of The Netherlands Organisation of Scientific Research (NWO). The objective of the Indian Ocean Programme (IOP) is 'to study the effect, on a spatial and temporal scale, of the monsoon on the climate system in the northern Indian Ocean'. The programme comprises five projects , A, B, C, D, and E, which are briefly described below.

Within the programme two countries are selected for a partnership in marine science. The pragmatic philosophy is that the overall 'return' of the planned IOP can be increased by combining the SOZ funded long term basic research with the more applied, short term objectives of development aid related research. The countries selected are Kenya and Pakistan. The approach of these partnership-programmes is sustainable development, transfer of know-how and infrastructure building through the execution of a joint research effort. The partnership programmes will be published separately.

The dynamics of the atmosphere and the ocean are but little understood, no matter the tremendous effort the international scientific community has put in resolving its mysteries. As we are all aware these days the urge to comprehend the atmospheric and oceanic systems of our planet is no longer a matter of scientific curiosity, it has become dramatically evident that only by understanding those systems we may be able to control and avoid ecological disasters that threaten survival, not just of human society but also of the planet itself.

The ocean is a vast reservoir of living and non-living resources, which play a major role in transport, defence, communications and recreation while they exert a great influence on global climate and pollution. The environment is thought to be changing on a scale hitherto unexperienced by mankind. Only by increasing our understanding of global and regional marine processes we may be able to avoid catastrophies.

A. Research of the continental shelf and the coastal ecosystems in Kenya

With this project we will be looking closely into the effects of the monsoonal system on the ecology of the coastal waters of Kenya. From November till March the northeast monsoon prevails and from May till September the southeast monsoon. In the Northeast Indian Ocean the water circulation reverses with the change in wind direction: during the southeast monsoon an East-African coastal current is heading north pushing great amounts of water with enormous speed from 4° S towards the Arabian peninsula; during the northeast monsoon there is no East African coastal current,

hence no upwelling. The southeast monsoon and East-African current generate a strong upwelling on the coasts of Somalia and the southern Arabian peninsula. Cold, nutritious water from the deep is pushed to the surface, resulting in increased biological productivity. Although less constant and less powerful, upwelling also occurs off Kenya. During the northeast monsoon the biological productivity diminishes in the coastal regions and conditions prevail that are akin to 'marine desserts'.

Nothing is known about the effects of this unique reversal of oceanic circulation on the ecosystems of the Kenyan coast. The project not only takes stock of the marine fauna and flora but also tries to gain a clear understanding of the physical, chemical and biological processes in this region. The productivity of the Kenyan coastal waters and its determining factors such as current patterns, contents of nutrients and light penetration will be examined. It will be checked whether production in the coastal region is exchanged with the deep sea, which is of great importance regarding the global effects of an increase in atmospheric CO_2.

The factors that determine productivity also include the influence of creeks and rivers. The mangroves along the banks are highly productive and act as nurseries for crustaceans and fish and provide coastal waters with nutrients. The exchange between these systems and coastal water is also seasonally determined (e.g. by the rainy season) specific effects, however, are unknown.

The research of the coastal waters as well as the exchange with creeks and rivers will be supplementary executed from the RV 'Tyro' and from a coastal base near Mombasa. Close collaboration will be estabilished with Kenyan research scientists of the Kenya Marine and Fisheries Research Laboratory In Mombasa.

B. Monsoons and pelagic systems

In the Northwest Indian Ocean the monsoons reverse the surface circulation every half year. During the southwest monsoon in summer, strong upwelling occurs along Somalia and the Arabian peninsula. Massive algal blooms develop and are driven far into the open Arabian Sea. The organic material sinks below the productive upper layer and the decay of this matter decreases the oxygen concentration at intermediate depths. During the northeast monsoon in winter, upwelling is absent and poor blue waters prevail. The oxygen profile is very similar in the Red Sea but water temperature is above 20°C down to the bottom, because the shallow Strait Bab-el-Mandab prevents cold, deep water to enter from the Indian Ocean.

The extreme seasonality and the extensive oxygen minimum zone in the Northwest Indian Ocean are unique and invite a study of the dynamics of the pelagic systems. During the International Indian Ocean Expedition of 1959-1965 productivity estimates were scanty and plankton was collected from the upper 200m only. Therefore, a series of cruises is planned involving measurements with modern techniques of a large number of biological and chemical variables on water and plankton samples down to depths of 1000 or 2000m. The research plan comprises two main themes, a quantification of the carbon flux and biogeographical studies. In the latter, distribution and taxonomy of plankton will be studied to test whether species known from other oceans are really missing in the Indian Ocean. Overwintering populations of typical upwelling species will be traced at depths near the oxygen minimum (500-600m), and factors influencing their life strategies will also be examined. The plankton composition in Strait Bab-el-Mandab should be studied, to see whether the impoverished fauna of the Red Sea is due to mass mortalities of important species by high temperature, or also by eventual lack of oceanic species in the summer undercurrent, with water originating from the upwelling areas.

The carbon flux part of the programme is a pilot study for the Joint Global Ocean Flux Study in the Northwest Indian Ocean (planned for 1994/1995) and will cover most of the core measurements of that international programme. Distribution and growth rates of different algal species will be related to hydrographical conditions, and monitoring of chlorophyll concentrations will facilitate the interpretation of satellite images for mapping phytoplankton booms. Recycling of nutrients by bacteria and by animal plankton will be compared with 'new' production caused by upwelling. Faecal pellets digested by larger plankton and by lantern fishes and collected in traps floating below the productive zone, should give a measure of the loss of carbon to depth. This is of importance to estimate the buffering role of the oceans with regard to the concentration of carbondioxide, the gas predominantly responsible for the present increase of the greenhouse effect. Special attention will also be paid to accurate determinations of dissolved organic carbon, a key variable in the capacity of the oceans to store CO_2. In addition, concentration and dynamics of N_2O, another gas contributing to the greenhouse effect, will be studied. The NW Indian Ocean is believed to produce a substantial part of global N_2O.

C. Tracing a monsoon induced upwelling system

The Northwest Indian Ocean and the Arabian Sea have properties that are unique in the world, namely seasonally reversing monsoons and related upwelling (see before, under A). Upwelling systems are of great importance, as they are directly related to global climatic change, mineral and hydrocarbon exploration. This can easily be understood by realising that during the upwelling season the biological productivity increases enormously. After death organic matter sinks to the seafloor, where it disintegrates, consuming considerable amounts of oxygen ('oxidation'). The result is a so-called Oxygen Minimum Zone (OMZ) on the seafloor, a potential site for the formation of hydrocarbons. It is also the place where high concen-

trations of minerals such as phosphates, opal and uranium may be found.
From previous deep-drilling in the ocean floor in this area, we know that the upwelling system, and thus the actual climatic conditions, were established some ten million years ago. The sediments and the incorporated skeletons of minute microfossils recovered during these drilling campaigns faithfully record subtle changes in upwelling intensity over this period. Careful studies of these sediments thus allow us to interpret past conditions and extrapolate the findings to the future.

Many signals contained in the fossil sediments are, however, still little understood. Bearing in mind the geological credo that 'the present is the key to the past', the scientific cruises described in this chapter, aim at a systematic and careful study of both the upwelling and the non-upwelling situations. This is achieved by sophisticated sampling- and measurement procedures throughout the water column and the uppermost part of the ocean floor. Techniques include CTD (conductivity, temperature, depth) measurements, plankton sampling by means of a multinet and determination of nutrient concentrations. Large funnel-shaped instruments (sediment traps) will be stationed at various depths in the water column, anchored to the seafloor. These will remain there for six months, enabling us, after retrieval, to quantify the amount of organic matter which descends to and eventually reaches the seafloor. The seafloor itself will be sampled from the ship by round boxes (box cores) and long tubes (piston cores) which sink into the soft clays and, upon retrieval, supply us with a core of undisturbed sediments. These 'books' of the earth history are the recorders of fluctuations in the upwelling system over a period covering the last 10-250 thousand years.

Integration of all data, collected on board and in the shore-based laboratories, will lead to a better understanding of the system, both in the past and projected towards the future.

D. The geological study of the Arabian Sea

1. Late Quaternary productivity and the dynamics of the Oxygen Minimum Zone in the northeast Arabian Sea.

The record of the climate of the past and of its change to that of today is locked in the sediments of the ocean floor. By carefully analyzing the sedimentological, geochemical and biological 'fingerprints' that are left in sediment cores taken from the bottom of the sea we should be able to establish changes in the physics, the chemistry and the biology of the Northwest Indian Ocean. The latter provide clues to changing environmental conditions (climate, primary productivity, nutrients) over the lengths of intervals cored, i.e. back in time. The strongest imprint of environmental change is preserved in the zone of highest productivity, with the greatest numbers and variety in organisms, where consequently oxygen consumption is and was highest. These so-called Oxygen Minimum Zones (OMZs) are found in water depths roughly between 200 and 1000 m and will be the focus of our attention. We thus will sample largely the continental slopes of Pakistan and Oman and the upper slopes of the Murray and Owen Ridges that reach up into the OMZ. The reason for working on both the Pakistani and Omani sides of the Arabian Sea is that in this way we will be able to distinguish and compare the effects of the northeast and of the southwest monsoon which are expected to have been differently influenced by climatic change at the turnover from glacial to postglacial time.

2. Depositional architecture and sediment facies of the middle and lower Indus Fan

The internal structure and development of submarine fan systems, specifically their distal parts, are not understood in detail. Since submarine fans are potentially important hydrocarbon reservoirs, the study of these systems should help establish models for their exploration. The study entails the analysis of the internal structure of the southern Indus Fan by high resolution seismic profiling and by taking sediment cores from fan channels, channel levees and sheet deposits. This part of our cruise will be executed exclusively in international waters in the deeper parts of the Arabian Sea.

E. Biology of oceanic reefs, Seychelles

The expedition to the Seychelles in the central Indian Ocean intends to examine the biology of coral reefs from different angles. The research in this 'umbrella-project' contains biogeographical, taxonomical, ecological and educational aspects.

The marine population dominated by coral will be explored along with the great variety of other habitats found at the reefs. From a biogeographical point of view the region shall be studied as an intermediate area between the Indo-Australian zone, East Africa and the Red Sea. This research will be based on the examination of various groups of organisms, in particular algae, sea grasses, sponges, sea anemones, stone corals, soft corals, worms, crustaceans and echinoderms. Of these groups taxonomical studies will be made also, which are to be connected with ecological aspects (such as local distribution patterns, population and the occurrence of symbiosis), biochemical studies and ecomorphology. The ecological research will be concentrated on the distribution ecology by study of the distribution of dominant organisms of the above mentioned groups.

Some special aspects will come up within this project, for example fisheries biology, the study of forms of symbiosis and the structure of population. The central topic in this project is: What distinguishes oceanic reefs from various, non-oceanic reefs that occur in the

Indonesian waters and the almost similar reefs in the Caribbean? In previous years both areas were explored by the same group of Dutch scientists which will facilitate this research. Such comparative research is of value for a better understanding of reef biology and tropical marine biology in general. The reinforcement of this understanding is essential for efficient control of the natural resources of the tropical seas and the protection of the marine environment.

Several items of the research programme will be realized in such a way that the results will be of optimum value for the aims of the Environmental Management Plan of the Seychelles 1990-2000 (published by the government of the Seychelles in October 1990). For this reason a more detailed programme will only be available after consultation with the departments responsible at the Seychelles, to give them the opportunity to put forward specific wishes and ideas.

During the expedition, next to scientific research, attention will be paid to underwater photography. Underwater videos will be made for educational purposes and for the general public.

1 Introduction

Looking at Earth from space, the planet appears as a sparkling gem against the empty blackness of the universe. Sunlight reflects the uniqueness of the planet in bright blues and whites, the colours of water in solid, fluid and gaseous form. Water is *conditio sine qua non* for life in the biological as much as in the geological sense and in a complex and intricate way lithosphere, hydrosphere, atmosphere and biosphere have kept each other in dynamic balance, already for billions of years. This balance, however, may now be upset by the uncontrolled proliferation of life's most successful form and by his excessive demands on the natural system.

Modern man's activities, large scale burning of fossil fuels, clearing of vast tracts of vegetation, global dispersal of chemical and toxic waste, overgrazing and overfishing have raised concern about their long-term effects. This is clearly expressed in the Bruntland Commission's report 'Our Common Future', issued by the World Commission on Environment and Development. The report introduces the concept of sustainable development, i.e. economic growth maintained within the limits set by the environment in the broadest sense. Environmental protection and economic development are considered to be complementary rather then antagonistic processes.

In the Netherlands the environment is subject of great public concern, has become one of the cornerstones of the national policy, and figures high on the political agenda. Recently this has been expressed in a number of policy papers such as the 'National Environmental Plan', 'Nature Policy Plan' and 'A World of Difference', the latter issued by the Ministry of Development Aid. In the Netherlands environmental concern encompasses the marine domain and this is expressed by a substantial investment of capital and manpower in marine research. Marine research in the Netherlands is not just restricted to coastal waters to protect the coastal zone and to preserve national livelihood and wellbeing, it extends over the global ocean to monitor and understand its dynamics and to wisely harvest its vast resources. As a rich and responsible member of the brotherhood of nations the Netherlands should share the knowledge thus gained for the benefit of all, not in the least the less developed nations.

1.1. The importance of the marine environment

The marine environment is of vital importance to the continued well being of mankind. Some forty percent of the world's animal protein is derived from the sea. Mariculture is expanding worldwide. Offshore oil and natural gas reserves are currently substantial sources of energy which are being tapped by advanced technology. The potential of other undersea minerals is being explored and evaluated. Some two thirds of the world's population lives in the coastal zone and over half of the world's coastlines are eroding. Much of society's waste ends up in the marine environment. It is obvious that especially the coastal zone itself is an important resource where the concentration of socio-economic activities frequently place conflicting demands. This results in a degradation of this important resource. Human interference has major impacts on coastal zones. The needs of countries to develop coastal zone management plans are growing as the human population increases.

Management of the marine environment presupposes a sound insight in and knowledge of the physical, chemical and biological conditions. Measures to reduce the effects of human activities require information on the sources of pollution and how these affect the environment. Effects and the measures taken to counter them must be looked at in the context of the ocean's tolerance and capacity. Marine science addresses coastal protection as well as coastal ecosystem management, aquaculture and coastal pollution by providing a sound basis on which such management plans can be formulated. As a consequence marine science has a vital role to play in achieving sustainable management of the ocean, coasts, shelves and deep sea, and in wisely harvesting its resources.

The rapidly increasing human population also affects the global environment by its increased exploitation of resources and discharge of waste. Sustainable development requires a detailed and precise knowledge of the resources, their distribution, abundance and potential yields. In this regard it is important that each coastal and oceanic state develops an adequate capability in marine science if the health of the global oceanic environment is to be maintained and its resources not depleted or degraded.

In turn the global human population itself is also affected by the processes in the world's oceans. The world's oceans are an important factor in climatic change as a fundamental component of the systems controlling global weather and climate. Major impacts of climatic change are expected to occur in coastal zones, near-shore areas and lowlands. Predicted impacts of climatic change may result in dramatic changes in ocean resource distribution and productivity, in coastal infrastructure associated with marine transportation systems,and in an increased frequency and severity of natural hazards in the coastal zones of the world. Not only are developing countries vulnerable to such changes, but unlike the more industrialized nations of the world, many lack the necessary capabilities in marine science which will enable them to address and plan for the predicted adverse impacts of such changes. The challenges posed by these changes necessitate both increased levels of investment in the global marine research and monitoring infrastructure as well as increased international co-operation. Only by 'pooling' our capabilities on an international level we will be able to understand the processes which link the climate and the oceans and by this understand how such changes and their potential impacts may be mitigated or avoided.

The oceans offer mankind a vast store of little-developed material resources. Modern marine research is generating new knowledge of what exists in and under the sea. New technology makes it feasible to reach and to extract or harvest natural resources that were previously inaccessible. Although the present level of exploitation of the oceans is growing rapidly, the potential is still enormous.

Man also urgently needs to establish the criteria for making the necessary choices among the many possible courses of action. These criteria are also necessary to implement the laws and institutions required to effect these choices. We must be able to prevent and correct mistakes caused by man's greed and ignorance. Among other things this means reduce, or preferably stop, the discharge of effluents, radioactive waste and other hazardous substances, and prevent accidents involving oil and chemicals. It seems that mankind's unwise use of the sea is about to reach the point of no return. This frightening situation has caused a new willingness to preserve this unique environment.

1.2. The Netherlands Indian Ocean Programme

The Indian Ocean is the world third largest ocean, 73 million km^2, one seventh of earth's surface. Some of the world's oldest and most densely populated countries fringe its northern rim.

When the British Challenger undertook her famous round-the-world cruise from 1872 to 1876, she omitted the northern half of the Indian Ocean. The number of oceanographic expeditions in the early days of modern marine research are few. Noteworhty are the cruises by the Austrians aboard 'Novara' in the 1850s, the Germans aboard 'Valdivia' (1898-1899), 'Gauss' (1901-1903) and 'Planet' (1906-1907), the Dutch with 'Snellius' in the late 1920s and early 1930s, biological and physical research by the British 'Discovery II' on her way to and from the Antarctic in the 1930s and 1940's; the British John Murray Expedition on board the Egyptian 'Mabahiss' (1933); hydrographic surveys of the British Royal Navy; the Swedish deepsea expedition 'Albatross' (1947-1948) and work done by the Danes with 'Dana' (1928-1930) and 'Galathea' (1950-1952). None of this research was done in a systematic way and sometimes twenty or thirty years elapsed between two observations in the same region. To overcome this situation the highly successful International Indian Ocean Expedition (IIOE), an initiative of the ICSU Scientific Committee on Ocean Research (SCOR), was conceived. The expedition took place during 1959-1965 and was coördinated by the newly established Intergovernmental Oceanographic Commission of UNESCO after its foundation in 1960. The expedition had a major scientific as well as social impact. It gave the first general overview of the Indian Ocean and it laid the base for the marine science infrastructure of the region's leading countries such as India and Pakistan.

Since the IIOE international research in the Indian Ocean was limited. Exceptions, however, are the activities of the deep sea drilling programmes: DSDP, 1968-1975; IPOD,1975-1983; and currently active ODP, 1985-present. Furthermore research from especially French, German and British research vessels passing the area as well as research carried out by the USA, USSR and the Indian Ocean nations India and Pakistan has been important. In the nineties a number of international initiatives related to Global Change will take place in this area. Several research groups are now discussing new programmes such as OMEX(Ocean Margin Exchange) in the framework of International Geosphere Biosphere Programme (IGBP) and Joint Global Ocean Flux Studies (JGOFS). In the JGOFS-community it is learned that the study of fluxes of carbon and associated elements in coastal oceans and marginal seas is a critical requirement for any programme dealing with global budgets. So far, the magnitude of the flux of organic matter from the coastal zone to the open ocean, which may be a significant sink of carbon, is uncertain. Part C of this programme is placed within the JGOFS Indian Ocean Programme

The overall scientific objective of the IOP is the study of the effect, on a spatial and temporal scale, of the monsoon on the climate system in the research area. The following research projects are developed and described in chapter 3:

- Monsoons and coastal ecosystems in Kenya
- Monsoons and pelagic systems
- Tracing a seasonal upwelling
- Geological study of the Arabian Sea
- Biology of oceanic reefs

1.3. Sustainable development in marine science

From 1982 to 1987 the Dutch and Indonesian governments provided the ways and means for the so-called Snellius-II Programme. Within this partnership in marine science the Netherlands Marine Research Foundation and the Indonesian Institute of Science executed the Snellius-II Expedition (1984-1985). The aim of the programme was to develop, execute and elaborate a joint research effort in eastern Indonesian waters. The innovative element was the transfer of knowledge, infrastructure building, as well as the 'translation' of the results to the public, politicians and scientists. The Snellius-II approach was a successful one and is internationally recognized as such (see Proceedings of Snellius-II Symposium Theme 1 to 5 published in the Netherlands Journal of Sea Research, 1988-1990).

It is important to realize that in marine science the dividing line between applied science, on the one hand, and basic science on the other, is tenuous at best. Consideration of marine issues immediately demonstrates that the two are inextricably linked and that attempts to separate them are artificial and ineffective. An important aspect of future directions in marine science must encompass the integration of open ocean research programmes with those on shelf seas and in the coastal zones.

To study open ocean processes in isolation or separately from processes in coastal zones is counterproductive in the face of global climatic change and possible rise in sea level.

Different countries have different needs and possibilities in marine science. SOZ has published (1988) a Marine Science Country Profile for The Netherlands. The report describes the scope of marine science in a national context and sums the existing marine science capabilities. In some developing countries marine science capabilities are well established, in others funding is limited and is largely directed to the investigation of immediate, resource related problems. Little is invested either nationally or internationally in strengthening the capabilities of such countries in addressing more broadly based research problems. It is known that the limited national investment in science education in many countries frequently results in general shortages in skilled scientific and technical manpower.

To participate as partners in marine science each country needs qualified personnel, an adequate infrastructure including equipment as well as the capability to maintain it, research programmes and information systems together with a broad approach in marine science. This has to be based upon an agreed high international level. By its very nature marine science is not confined within specific boundaries such as countries or regions. Marine scientists must therefore, be able to draw upon the scientific contributions from all states if they fully want to participate in global activities and if marine science is to address global issues.

The need for partnerships in ocean sciences and services for sustainable development has a multiform and practical basis. This is among others the consequence of the transnational nature of marine problems, the effects of the regime under the Convention on the Law of the Sea, Global Change related as well as other large international research programmes and the sharing of the resources. These factors necessitate a new holistic approach for the co-operation between developed and developing countries. This approach is similar to the one applied during the Snellius-II Programme. In such an approach education in marine sciences for example is not considered separately from research and infrastructure building. Moreover, open ocean issues should not be treated as distinct from those in the coastal zones and global problems should be addressed in concert with national and regional concerns. Within such a partnership certain elements are essential. These are the transfer of information, an increased and more effective technical communication between scientists at national and international levels, the exchange of ideas between the public, politicians and marine scientists, and the collaborative interaction between marine scientists in different disciplines.

The responsibility for the development of a marine science capability rests ultimately with each individual country. Nevertheless, countries with well developed marine science capabilities have a responsibility to assist in the development of similar capabilities in less developed nations. Whenever industrialized countries support marine research in developing countries, the prevailing view seems to be that only applied research should receive support. Moreover, the needs in marine science are generally perceived similar along lines to the needs in other scientific and technological disciplines: more money, more trained and skilled manpower, more equipment, more training programmes, both formal and informal, more scholarships, more overseas attachments, and a greater commitment on the part of the general public and politicians to the development of marine science. Frequently such inputs are not properly evaluated in terms of assessing their impacts on performance, achievements and the development of marine scientific capabilities in developing countries. Often expensive equipment, including research vessels, is provided through donor agencies while problems of maintenance or recurrent budgets prevent its proper use in the development of marine science.

Within the Dutch IOP two countries were selected for a partnership in marine science, Kenya and Pakistan. The pragmatic philosophy is that the overall 'return' of the planned IOP can be increased by combining the SOZ funded long term basic scientific research activities with the more applied, shorter term objectives of development aid related research activities. The approach of these partnership-programmes is sustainable development, transfer of know-how and infrastructure building through the execution of a joint research effort. This was also the Snellius-II approach.

The aim of the programme in Kenya will be to study the effects of the monsoon on coastal marine ecosystems, in particular the changing effects of the two contrasting weather patterns through their impact on land runoff and ocean circulation. Primary production and the fate of organic matter as well as the exchange with land and deep ocean will be studied. Human impacts (pollution, erosion, mangrove felling) on these processes will also be considered. The following seasonal effects of climatic change on coastal ecosystems will be studied:

- The seasonality in productivity of surface waters and sedimentation.
- Inland erosion and erosion of degraded mangrove systems and increased siltation of coastal areas.
- Changes in growth of seagrasses and corals due to siltation, increased nutrient levels and temperature increase.
- Changing inputs of nutrients, particulate matter and inorganic pollutants from (semi-) terrestrial origin, including mangrove systems.

The important added value of the present programme for Kenyan scientists is the increased knowledge on basic compartments of Kenya's coastal ecosystems which are hitherto unknown. For Kenyan scientists the participation in the IOP will mean access to a modern oceanographic research vessel and its application to the study of environmental issues. The ocean-going expedition is planned to be a core part of the five years marine science programme between Kenya and The Netherlands. The ocean-going programme is financed by SOZ; the coastal and pollution programme has to be financed by Development Aid.

The outline of the joint programme with Pakistan is still under discussion. The seven years programme has been divided in two phases. Phase 1 (1992-1993) comprises the SOZ-funded ocean-going research project the 'Geological Study of the Arabian Sea' and a pioneer fellowship-programme. The second phase (1993-1998) will comprise a coastal research programme, in which a study of sub-marine and terrestrial mud volcanoes is included. This part as well as the follow-up fellowship programme have to be funded by other sources such as Development Aid.


76
76

2 Organisation of the Programme

The Netherlands Indian Ocean Programme was developed by the Dutch marine sciences community. Representatives thereof and staff responsible for logistics and technical support together form the Indian Ocean Committee (see Annex 1). This chapter describes items of general interest and directives, which are to be taken into consideration during the execution of the Programme. Detailed information will be given in The Netherlands Indian Ocean Programme Guide.

2.1. Schedule

The Programme will be carried out in the North West Indian Ocean between May 1992 and April 1993 (Figure 2.1) and thus operations cover two monsoons: the Northeast monsoon (November - March) and the Southwest monsoon (June - September) for the northern part of the Indian Ocean and the Northeast monsoon and the Southeast monsoon for the southern part of the Indian Ocean. During the SE - SW monsoon storms are active in July and August.

The main part of the programme will be executed on board R.V. Tyro. A landbased project is planned in June/July 1992 in the coastal area of the Republic of Kenya. During the Programme the 'Tyro' will make port calls in Port Said (Egypt), Mombasa (Kenya), Djibouti (Djibouti), Victoria (Seychelles), and Karachi (Pakistan) (Table 2.1).

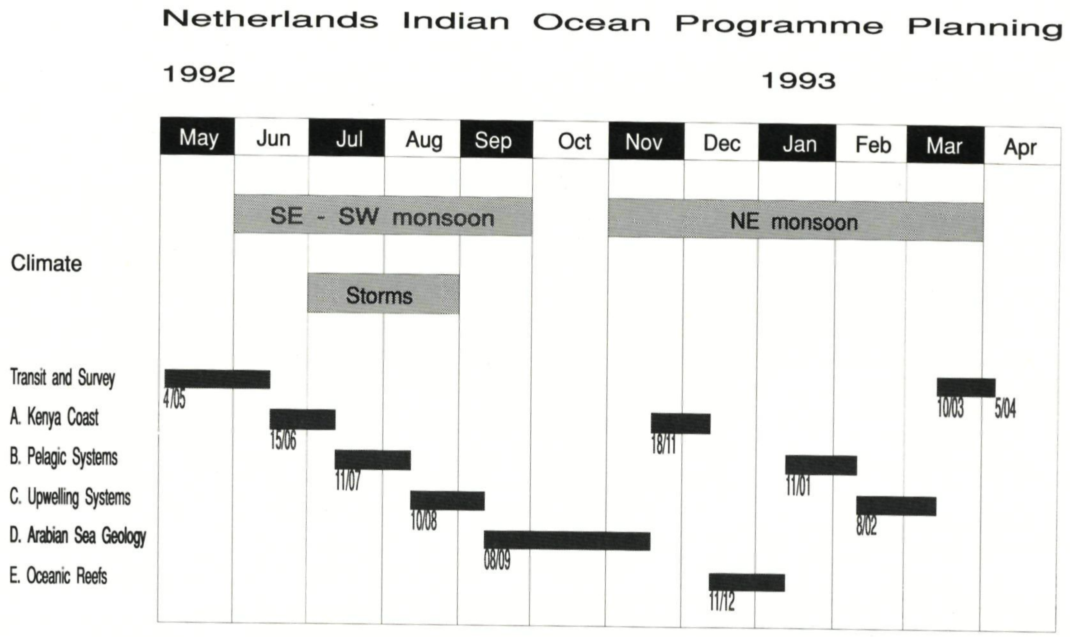


Figure 2.1. Indian Ocean Programme Planning

Table 2.1.				Ports of Call Planning	
Port	Country	Date in	Date out	Start of Project	
Den Helder	Netherlands	25 Apr '92	4 May '92	Mobilisation	
Port Said	Egypt	19 May '92	21 May '92	Transit and Survey	
Mombasa	Kenya	12 Jun '92	15 Jun '92	Kenya Coast	A
Mombasa	Kenya	09 July '92	11 July '92	Pelagic Systems	B
Djibouti	Djibouti	08 Aug '92	10 Aug '92	Upwelling Systems	C
Victoria	Seychelles	06 Sep '92	08 Sep '92	Arabian Sea Geology	D
Karachi	Pakistan	01 Oct '92	04 Oct '92	Arabian Sea Geology	D
Karachi	Pakistan	27 Oct '92	29 Oct '92	Arabian Sea Geology	D
Mombasa	Kenya	16 Nov '92	18 Nov '92	Kenya Coast	A
Mombasa	Kenya	09 Dec '92	11 Dec '92	Coral Reefs	E
Victoria	Seychelles	09 Jan '93	11 Jan '93	Pelagic Systems	B
Djibouti	Djibouti	06 Feb '93	08 Feb '93	Upwelling Systems	C
Djibouti	Djibouti	08 Mar '93	10 Mar '93	Transit to the Netherlands	
Den Helder	Netherlands	29 Mar '93	05 Apr '93	Demobilisation	

Table 2.1.
Ports of call

2.2. Facilities

The Netherlands Marine Research Foundation (SOZ) will make available her complete pool of oceanographic equipment, including the containerised research vessel Tyro (Figure 2.2). All containerised laboratories will be used, not only on board ship, but also to set up a land-based laboratory facility in Kenya.

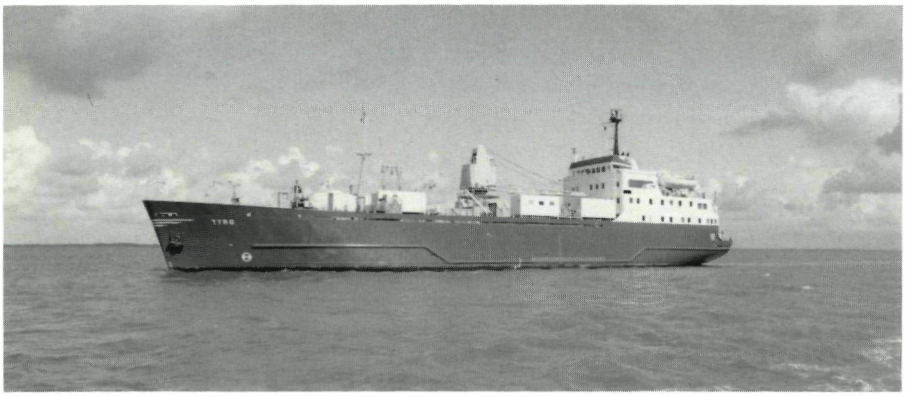


Figure 2.2.
R.V. TYRO

Besides the containerised laboratories a variety of oceanographic equipment will be available on board the 'Tyro'. Maintenance and repair of the equipment as well as the technical assistance on board the ship is subcontracted to the Netherlands Institute for Sea Research (NIOZ). Apart from SOZ's equipment, participating research organisations will bring their own laboratory equipment as well.

2.3. Responsibilities

The SOZ is responsible for the Programme as a whole. The responsibility for the execution of the expeditions is delegated to the Indian Ocean Committee (IOC) of the SOZ. Participation of scientists from other countries needs IOC´s endorsement. Scientists from participating countries are considered members of the Dutch team. The SOZ has appointed an Operational Co-ordinator. The SOZ is also responsible for public relations. Visa, travel arrangements and customfacilities are in principle handled through the SOZ-office.

2.4. Data and Publications

All data, specimens and other materials obtained during the Programme will be shared according to agreements and regulations of participating countries. Two years after the completion of the project all data will be released to interested third parties, including oceanographic data centers. From then anyone may freely use the information, provided the data are cited properly, with reference to the scientist responsible for the 'borrowed' data in the acknowledgement of the final document. Any scientist whose data are being used will be offered a co-authorship in case she/he has made a significant contribution. The results of the Programme will be published as follows:

a. *Shipboard Reports* to be finished at the end of each cruise, containing pertinent information on the activities, data and specimens obtained during the cruise, reports on lost and damaged equipment and, if possible, preliminary results. This type of report has a provisional lay-out and is distributed in a limited number by the chief scientist to SOZ and major participating institutes right after the cruise.

b. *Reports on the Netherlands Indian Ocean Programme*, a series comprising the following types of reports, for each of the five projects (NB. Part of the cover lay-outs may differ between projects, depending on bilateral co-operation and international context).

- *Cruise Reports* to be finished 6 months after the completion of the cruises of the project. A Cruise Report is the final version of the Shipboard Report, printed in a sufficient number of copies for distribution to all participants and interested parties. Projects with several cruises or parts combine the separate reports into one definite Cruise Report.
- *Workshop Reports*, with a collection of presentations on the results obtained so far by participants. To appear shortly after a scientific workshop, scheduled for each project within 1 or 2 years after the completion of the cruises in March 1993. These reports are both meant for stimulating the preparation of papers by the participants and as a preliminary overview of the results.
- *Data Reports* to be finished March 1985, two years after the completion of the cruises in the Indian Ocean. These reports have to list all the figures from the basic sampling programme, in appropriate style and units. If data on JGOFS core measurements are involved, files in recommended formats will have to be delivered to the JGOFS Data Bank on the NW Indian Ocean (to be established). All data will be clearly labeled to scientists responsible for processing of data and samples. Contributors have to include short accounts of the methods used and the accuracy obtained. It is expected that users of the Data Reports would obey the normal scientific obligation to contact the originator for permission to make further use of those elements of interest to them.

c. *Final publications.* Results will be published primarily in refereed international journals. In a later stage it will be decided whether there will be in 1995 a general symposium on the scientific results of the Netherlands Indian Ocean Programme 1992/1993, or whether smaller symposia regarding specific issues will be preferred. Proceedings will be published in issues of appropriate journals, rather than appearing in a separate book. All publications should be written in English. Co-authorship between Dutch scientists and scientists from the participating countries is encouraged. Five reprints (three for SOZ and two for the counterpart) should be submitted to the SOZ.

2.5. Training and Education

Besides transfer of scientific knowledge, assistance in education and infrastructure building are objectives of the Indian Ocean Programme. Funding of this still has to be acquired from, among others, Development Aid. For the core part of this Junior scientists and technicians of countries involved may be given the opportunity for education at Dutch research institutes, or on board training. The following training possibilities are suggested:

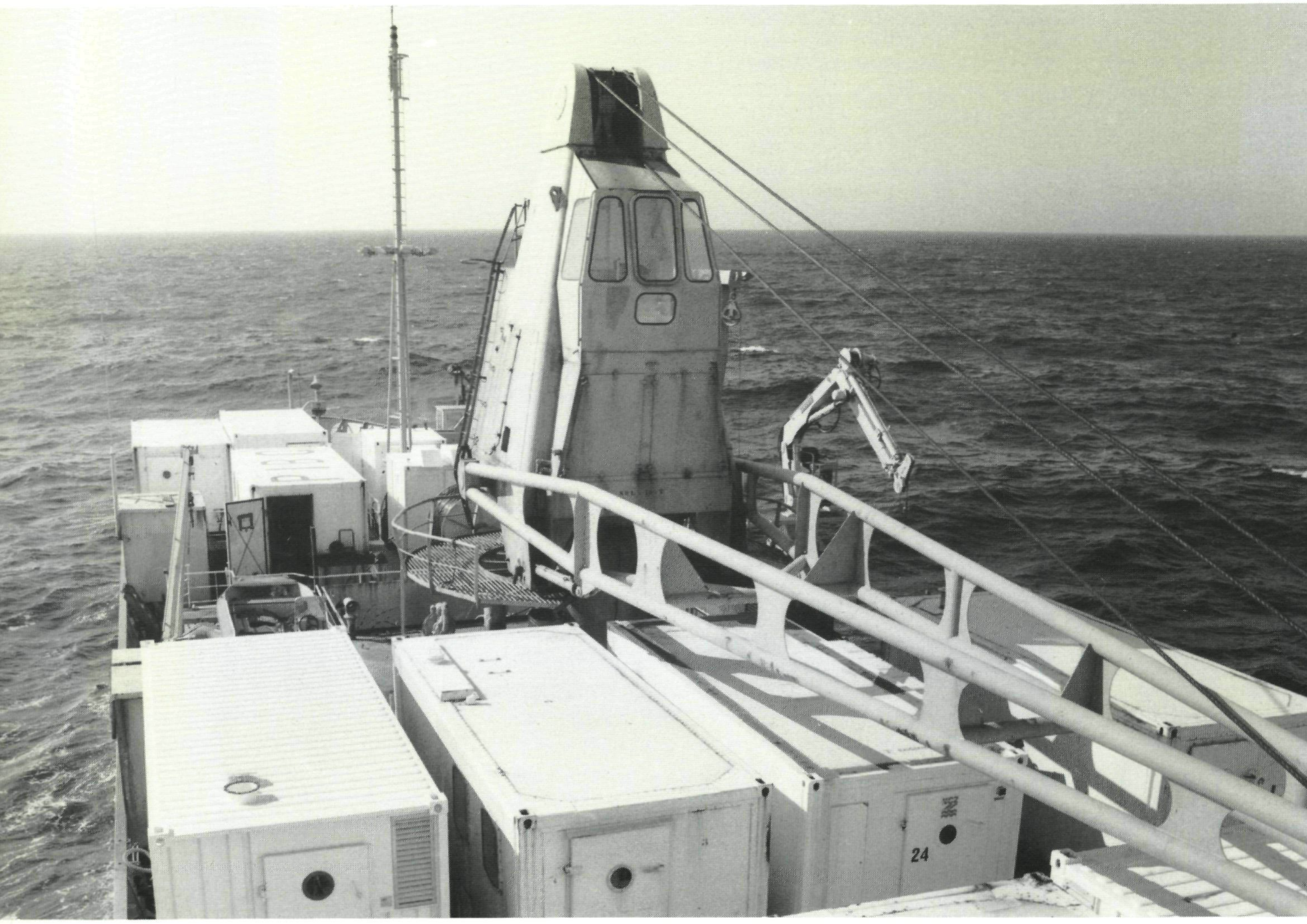
a. *Pre-expedition Training* for junior scientists and technicians on specific techniques or methodologies that will be used during the Programme. The training should take place in 1992 in relevant Dutch institutes for an approximately 3 months period.
b. *Onboard Training* during the Programme for both junior scientists and technicians on sampling, operating equipment, labelling and preserving samples, data recording, etc.
c. *Fellowships* for junior scientists during and after the Programme for analyzing samples, data handling, preparation of joint reports/manuscripts for publication.
d. *Long-term Academic Scholarships* leading towards Master or Physical degree programmes with Dutch universities for potentially capable candidates from the participating countries in the field of marine science, marine technology and other related fields.
e. *Guest lectures* at Universities of the participating countries. Dutch scientists will give guest lectures as much as possible before, during and after the Programme.

2.6. Budgets

The Netherlands Organization for Scientific Research promotes marine research in the Netherlands, among others, through the SOZ. The execution of the programme will be funded with a budget of 10.4 million guilders. A major part is needed for equipment and general support (such as the exploitation of the ship) (Table 2.2). A small part is made available for pre expedition training. Post expedition training and the other education funding have to be made available through other channels.

Table 2.2. Budget of the Indian Ocean Programme

Table 2.2.						(in kf)
Project	A	B	C	D	E	Total
Budget						
Ship	810	1.010	980	1.170	480	4.450
Technical assistance	317	395	385	457	186	1.740
General facilities	106	132	128	152	62	580
Maintenance	91	113	111	131	54	500
Travel and stay	315	165	185	225	110	1.000
Transport				15		15
Investment	270	216	244	316	54	1.100
Project exploitation	240	90	125	130	30	615
Post- and pre Programme						400
Total	2.149	2.121	2.158	2.596	976	10.400



3 Scientific Projects

The Netherlands Indian Ocean Programme consists of five scientific projects. These projects will be described in this chapter. The projects are numbered from 3 A untill 3 E.

The total coverage of the research programme will be over 6 million km^2 in the Northwestern Indian Ocean (Figure 3.1).

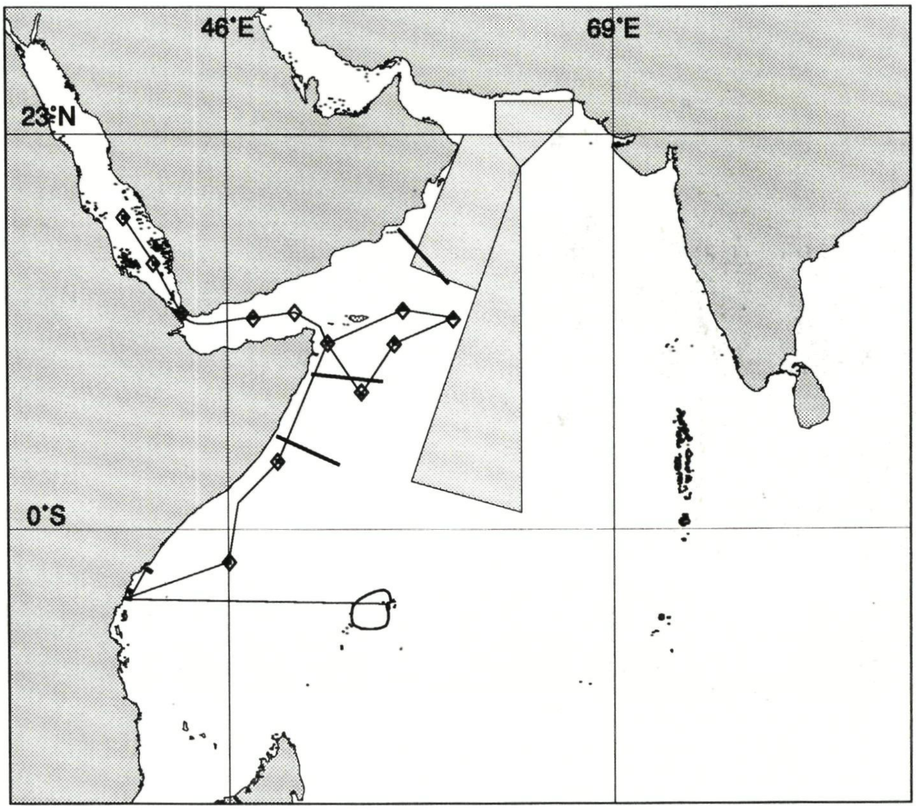


Figure 3.1. Netherlands Indian Ocean Programme

A

Monsoons and Coastal Ecosystems in Kenya

1. Introduction

Only very limited research has been done along the East African coast since the large efforts during the International Indian Ocean Expedition (1959-1975), which gave the first general overview of the Indian Ocean. Of a number of systems, such as the benthos, and of a number of dominant processes, such as primary production and sedimentation, nearly nothing is known. This lack of knowledge about the western margin of the Indian Ocean not only reflects on local management of coastal areas but also has more general implications.

Ocean margins, which comprise estuaries, coastal, shelf and shelf-edge components, are a globally critical land-ocean interface controlling the anthropogenic and terrestrial fluxes and fates of chemicals and biological production to and from the open ocean (Mantoura et al., 1991). The magnitude of the flux of organic matter from the coastal zones to the open ocean, which may constitute a significant sink of carbon, is uncertain. In a report of the JGOFS Planning Meeting in Paris, 1987 it is stated that 'the study of fluxes of carbon and associated elements in the coastal oceans and marginal seas would be a critical requirement for any programme dealing with global budgets'. The meeting agreed that the following topic should be considered among others: 'Temporal and spatial variability in primary production, its relation to satellite ocean colour measurements and to the balance between the production and consumption of organic matter'.

To bridge the existing gap in knowledge a number of initiatives are drafted both in Europe and the United States to develop coastal oceanographic research and to put it in the context of Global Change and climate research. In the US a national plan called Coastal Ocean Processes is in the making with as scientific goal 'to obtain a new level of quantitative understanding of the transports, transformations and fates of biogeochemically important matter on the continental margin'. In Europe several groups are now discussing new programmes such as OMEX (Ocean Margin Exchange) in the framework of the IGBP (JGOFS and LOICZ). The Kenyan Coast Study of the Netherlands Indian Ocean Programme may be situated in this international framework.

It is obvious that the East-African coast with its shallow shelf and its short distances between land and deep sea provides an extremely good location for studying exchanges along these margins.

1.1. International Co-operation

The project will be a major effort coinciding with the project Dynamics and Assessment of Kenyan mangrove ecosystems that started in 1990, a three years project of the Commission of the European

Communities. This is a co-operative project between the Delta Institute, the Catholic University of Nijmegen and a number of Belgian universities co-ordinated by the Free University of Brussels, the Kenyan universities of Nairobi and the Kenyan Marine and Fisheries Institute in Mombasa. This CEC-project results from the current Kenyan-Belgian Co-operation in Marine Sciences project running since 1985. With this project a scientific and logistic base in Kenya exists. A number of Dutch and Belgian scientists and a guest house are present in Mombasa and will support the CEC and the SOZ.

The important added value of the project for Kenyan scientists is the increased knowledge on basic compartments of Kenya's coastal ecosystems which are hitherto unknown. The expedition will mean for Kenyan scientists that they get access to a modern oceanographic vessel and its application for the study of environmental issues. The expedition is planned to be a part of a five year co-operation programme between the Netherlands and Kenya in which training and follow-up of the expedition are essential elements.

2. Scientific Rationale

The magnitude on the global scale of the flux of organic matter from land to the coastal zones of the ocean and further to the deep sea is uncertain. Terrestrial and littoral ecosystems may be a direct source of organic matter or may increase coastal production by exporting nutrients. Areas where freshwater input is small and where no upwelling exists are generally considered to be of little importance in the global carbon cycle. However, nitrogen inputs from rivers may be exceeded by other nitrogen sources such as nitrogen fixation or regeneration in sediments. Export from coastal systems with a narrow shelf may be much faster than from broad productive shelf areas where much of the organic material produced may be used on the shelf itself.

Although the East-African coast is not likely to be an area where significant amounts of carbon are transferred, it is interesting for several reasons. It borders the western Indian Ocean over several thousands kilometers. The productivity of its coastal waters limited mostly by nutrients and nutrient concentrations may be very different according to the season, depending on the monsoon. There are indications of upwelling occurring south of Somalia, but the contribution of new production relative to recycled production has not been investigated. Nitrogen fixation may be another non-negligible but unknown source of new nitrogen in these tropical areas. If, as expected, primary production is seasonal and strongly linked to the monsoon, there will be pulses of organic matter sedimenting to the benthos as well. The benthic productivity of the Kenyan shelf may therefore also be seasonal and also the export of organic material, especially in areas where the shelf is very narrow, to the deep sea.

The Kenyan coast offers a good environment to study coastal effects on productivity of oceanic ecosystems since two of the most important factors governing primary production, light and temperature, are nearly constant over the year. What varies are the composition of the oceanic water and the amount of fresh water that enters the coastal areas. At the Kenyan coast the main source of water is open oceanic water during the SE monsoon and coastal oceanic water during the NE monsoon. These two water types may have a much different composition since their contact with the coastal zone has a different duration. Especially the effects of various localized or diffuse land-based sources are much larger during the NE monsoon than during the SE monsoon. The amount of fresh water entering depends heavily on rainfall which is also linked to the monsoon.

Another last advantage of the Kenyan coast is that it has several well localized point sources of material which may be studied in greater detail: the two larger rivers Tana and Sabaki and the numerous mangrove creeks.

2.1. Objectives and Applications

The aim of this research project is to study the effects of the monsoonal regime on coastal marine systems, in particular the changing effects of the two contrasting weather patterns through their impact on land runoff and river flow and the reversing currents. Primary production and the fate of the organic matter produced as well as the exchange with the land and the deeper ocean will be studied. Human impacts (pollution, erosion, mangrove felling) on these processes will be considered as well.
The seasonal effects on coastal ecosystems to be considered are:
1) The seasonality in productivity of surface waters, the structure of pelagic and benthic systems and sedimentation and exchange processes.
2) Inland erosion and erosion of degraded mangrove systems and increased siltation of coastal areas.
3) Changes in growth of seagrasses and corals due to siltation, increased nutrient levels and temperature increases.
4) Changing inputs of nutrients, particulate matter and inorganic pollutants from (semi-) terrestrial origin, including mangrove systems.

The long-term changes that will be considered are changes in rainfall over the last 10,000 years, production of greenhouse gases and changes in coral growth related to sea-level rise. Two important problems due to climatic changes will be investigated. It has been shown recently that exposure to water temperatures over 30 °C for several months may lead to expulsion of the zooxanthellae from the corals, hence to bleaching, reduced growth and eventually death. The extent of bleaching in Kenyan waters is unknown. A second threat may be increasing phosphate levels due to pollution. Even small increases in phosphate may inhibit growth because polyphosphates compete with calcium carbonate in the formation of aragonite. Inhibited growth may reduce the ability to cope with rising sea levels.

The contribution of coastal wetlands to the greenhouse effect through the production of mainly methane is dependent on climate since their extent is mainly governed by rainfall. Measurements of the production of greenhouse gases by mangrove and seagrass-systems are scarce in general and absent from East Africa.

Deforestation and cattle ranching in the interior of Kenya has lead to an important increase of the sediment load of the rivers. The effects of sedimentation of silt on the reefs are especially visible in an extension of the seagrass-beds (Giesen & van der Kerkhof, 1984) and a reduction of the corals (Blom et al., 1985; Van Katwijk et al., 1989). Effects on the productivity of the coastal waters have not been studied yet. Such effects may be positive as well as negative: import of nutrients and oligo-elements may increase productivity but the increased extinction may decrease it.

Despite the presence of several marine parks and reserves research on the coral reefs is still fragmentary. This is partly due to the poor accessibility of some areas and logistical problems. The presence of a research vessel gives a unique opportunity to visit poorly known areas, especially in the north of the country.

The Kenyan coast is of importance to the economy of the country, especially by rapidly increasing tourism. The natural values are outstanding: the intertidal areas are wintering grounds for palaearctic birds and local populations of several sea turtles, including the leatherback and the dugong. A number of marine parks have been created and are well managed. These parks generate revenue for the local population and the country.

Human impact is expanding on the coast. Overfishing on the coral reefs (parrot fish and especially triggerfish) has lead to extension of sea urchins (*Echinometra mathei*) that predate on the living coral and enhance erosion of the reef. The proximity of touristical infrastructure directly and indirectly leads to more human pressure through an increase in fisheries and exploitation of corals and shellfish for ornamental purposes.

The mangroves are under human pressure as well, due to increasing exploitation. The wood is used for the production of tannins, as fire wood and for the construction of houses: there exists a centuries old trade between Lamu and Jemen for this material. In some cases mangroves have been cut for tourist development and ponds for aquaculture (e.g. in a FAO-sponsored project). The largest creeks in the country are the two creeks surrounding the fossil coral island on which Mombasa, the largest harbour of East Africa, is built. Both the

Kilindili and Tudor creek are used for the discharge of domestic and industrial waste.

2.2. Monsoons, Current and Upwelling

A characteristic feature of the hydrography of the Indian Ocean is the seasonal switch in flow directions caused by the monsoon winds (Figure A.1). These winds are influenced by the low pressure Intertropical Convergence Zone (ITCZ). The ITCZ moves to the north during the northern hemisphere summer due to the low pressure belt existing on the Asian continent then. From November until March the NE monsoon is blowing, from May until September the wind direction is southwest to southeast (SE monsoon).

The Indian Ocean basin can be divided into northern and southern sectors with 10°S as the dividing line. At this latitude a subsurface salinity minimum exists that extends from north of Madagascar to south of Java. To the north is the high salinity, high nutrient, low oxygen water of the monsoon gyre, to the south is the high salinity, low nutrient, high oxygen water of the subtropical gyre. The permanently west-flowing South Equatorial Current at 6°S to 20°S is partly diverted along the eastern Madagascar coast, becoming the Madagascar current. On approaching the mainland the SEC splits to form two coastal currents: the East African Coastal Current (EACC) to the north and the Mozambique Current to the south. That current later joins the Madagascar Current to form the Agulhas current.

During the SE monsoon, the EACC has a high flow velocity, up to 200 cm/sec, particularly in the upper 200 m of the water column; water transport may be up to 65 million m^3/s. This current causes an upwelling along the Somali coast, which is among the most extensive in the world and occurs in early summer. Upwelling is not restricted to the Somali coast. Ekman-type upwelling along the Arabian coast is also very extensive. According to CZCS images a maximum in surface chlorophyll is found there in August-September. Another more irregular upwelling occurs near the northern Kenyan coast and CZCS images showed a maximum chlorophyll content there in January, during the NE monsoon, which may be associated with river runoff after the long rains. This also happens during the NE monsoon at the northern ends of the Arabian Sea and Bay of Bengal.

In the Somali region the primary productivity during the NEM is roughly equivalent to that of the Sargasso Sea, while during the SE monsoon areas of upwelling have rates of primary production among the highest in the world's oceans. Seasonal contrasts in primary production as based on the depth of the euphotic zone, are predicted to occur in the area, which however was one of the areas unsampled during the International Indian Ocean Expedition during May-October. Pannikar (1970) shows abundant copepod biomass extending along the Somali coast in April-October. However, during the NE monsoon increased copepod abundance is found southwards, along the Kenyan coast. Again river runoff is suspected to be at the origin of this enhanced production.

The high productivity of the surface waters during the NE monsoon in Somalia is not reflected in higher organic matter in the sediments. This is because the shelf is narrow and offshore currents are strong. The organic matter is probably not recycled but transported into the northwestern basin and deposited at great depth. Whether this also happens in Kenya is unknown.

2.3. The Kenyan Coast

The annual migration of the Inter-Tropical Convergence Zone gives rise to the northeast and the southeast monsoon in East Africa (Figure A.1). Only off the Somali coast the easterly air movement during the SE monsoon is overridden by a westerly flow towards the Asian continent. Along the Kenyan coast the NEM season is between November and March, the SE monsoon season between April and October. The SE monsoons are characterized by high clouds, rain, wind energy and decreased temperatures and light. During the NE monsoons the situation is reversed (Figure A.2).

Due to the currents the major downwelling area and associated low nutrient waters are off Tanzania and southern Kenya. Downwelling occurs throughout the year but is strongest during SE monsoon when the current speeds are greatest. Upwelling occurs off northern Somalia during SE monsoon but breaks down during NE monsoon when the current direction switches. During NE monsoon currents

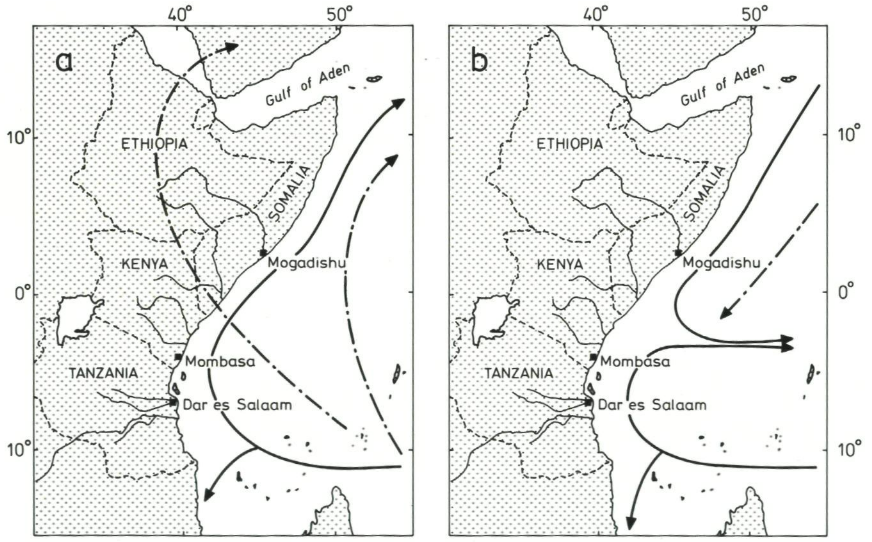


Figure A.1. Current patterns (solid lines) and wind directions (dashed lines) during (a) the SE and (b) the NE monsoons in the East African region.

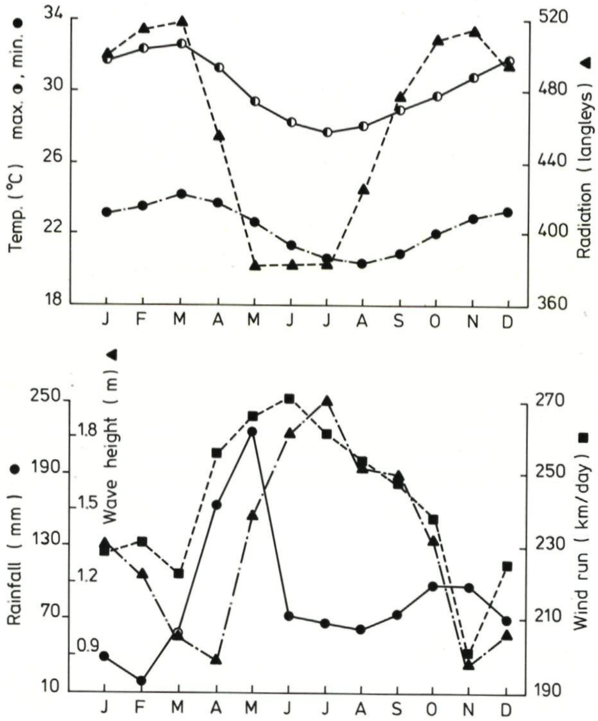


Figure A.2. Meteorological parameters in Mombasa. a: air temperature and solar radiation b: rainfall, wind run and wave height

leave the coast from northern Kenya where upwelling may occur. The differences in currents, up and downwelling, water temperatures and nutrients cause a north-south divide between the ecosystems along the coast. The southern section (Tanzania-Kenya) is dominated by coral reefs and benthic productivity associated with low-nutrient water. The northern sector (Somalia) has cooler nutrient-rich water and a greater predominance of planktonic productivity.

The coastal ecosystems in Kenya consist of: (1) a shallow shelf area (2) coral reefs (fringing reefs) along the entire coast, with extensive areas of seagrass beds on the sheltered parts of the backreefs and in lagoonal areas; (3) mangroves on the shores of the brackish parts of rivers and creeks along the coast; also seagrass beds occur here.

The continental shelf is narrow and the ocean is very deep close to the Kenyan coast. There is no information on the benthic ecosystems beyond the reefs and also with respect to the pelagic domain only little information is available: the classical picture is that these areas combine a low productivity with a high diversity but there is evidence of upwelling and higher productivity in northern Kenya during winter. The interactions between the off-shore and coastal areas and the impact of the monsoon on these interactions are unknown. How much material is introduced into the ocean and where it goes is unknown. The sedimentology of the Kenyan coastal zone is unknown. Because the tidal amplitude is rather large (approximately 4 m near Mombasa), there is an extensive intertidal zone between the reefs and the coast on many places; the substrate in this zone mainly consists of carbonate sands derived from eroding reefs. The productivity of these back-reefs is determined predominantly by the presence of seagrasses and microscopic benthic algae. On many places along the Kenyan coast, substantial seepage of freshwater occurs; as a result brackish water is often found in areas of seagrass beds. The system of reefs and seagrass beds along the Kenyan coast is interrupted in a number of places. Two large rivers debouch into the Indian Ocean: the river Tana in the north and the river Galana-Sabaki approximately in the middle part; both spring from the volcanic highlands around Mount Kenya and the Aberdare Range. Many smaller rivers from the neighbouring highlands run through the fossil coral beds which are present on many places along the coast, forming creeks with extensive mangrove growth. This is for instance the case near Lamu, Katungu, Kilifi, Mtwapa, Mombasa, Gazi and Shimoni.

Along the Kenyan coast the long rains normally occur in April and May whereas the short rains occur in October and November, at times of intermonsoon. During the rainy months terrigenous material enters the Indian Ocean, because of the high discharge from the rivers (Figure A.3). Especially the river Tana and the river Galana-Sabaki transport huge quantities of silt originating from the interior; The silt is spread along vast stretches of the coast and into the Indian ocean. In the estuaries and in the smaller creeks an extensive brackish water zone is often found; the residence time of the water in these systems is generally short.

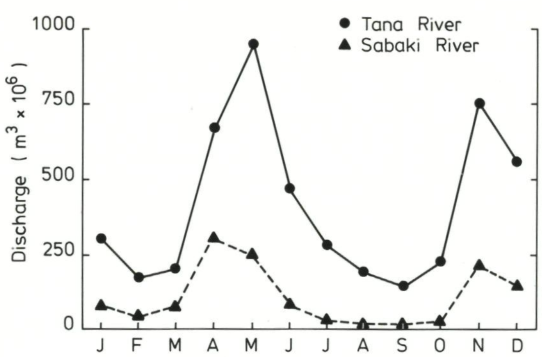


Figure A.3. Average monthly discharge from Kenyan Rivers Tana (1948 to 1979) and Sabaki (1952 to 1979). (Tana River Development Authority).

The mangrove ecosystem, characteristic of these silty brackish transition zones, mainly consists of woody plants associated with a characteristic fauna and flora. The salinity gradient resulting from the mixing of outflowing river water and the incoming sea water, regulates the presence of the various mangrove species. The system is open, with input of nutrients from the land and export of organic material to the sea. This organic material originates from a complex detrital food chain and is an important source of energy for numerous brackish and marine organisms (oysters and other bivalves, peneid shrimps and crabs, mullets and other fish species). Mangroves are nursery areas for several commercially exploited species.

3. Research Subprojects

The IOP in the Kenyan coastal waters consists of two main projects, one based on board Tyro to study processes on the shelf and one land-based in Mombasa to study the coastal processes. An additional project is concerned with pollution of Kenyan coastal environments.

3.1. Effects of the Monsoon on the Ecosystem of the Kenya Shelf

(Project manager: C. Heip)

The following questions will be addressed:

1) What is the productivity of Kenyan coastal systems and how does it change with the monsoon? How is the organic material produced used in the food web and how is the structure of the pelagic ecosystem dependent on season?
2) Are the expected contrasts in pelagic productivity reflected in changing benthic metabolism? Is there export to the deep sea?
3) Is the productivity of coastal waters dependent on export from rivers, seagrass and mangrove areas? How does this change with season and what is the human impact on these processes?
4) Are the size and biomass spectra of benthic communities in tropical areas different from those in temperate and boreal areas?
5) What are the dominant zooplankton and benthic species on the Kenyan shelf?

Three transects perpendicular to the coast are proposed (see Figure A.4):
1) Gazi transect
2) Tana transect
3) Kiunga transect

The Gazi transect in the south will provide the link with the land-based mangrove studies. Gazi is also well south of the South-Equatorial Counter Current, in an area where neither upwelling nor significant river input exists. The Tana transect covers the mouth of

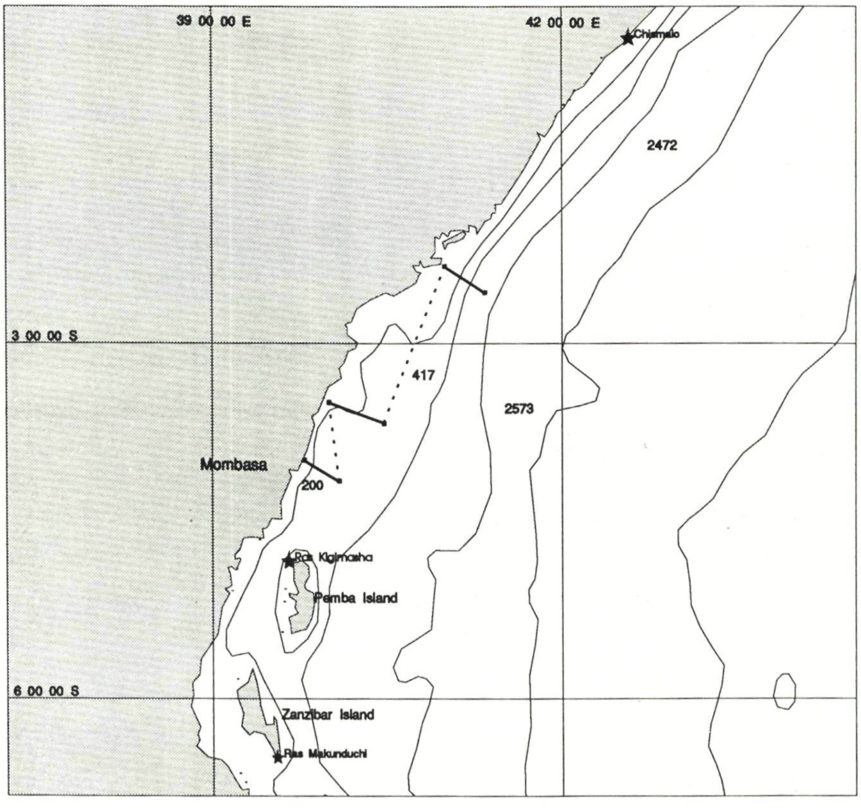


Figure A.4. Area map, showing the three transects Gazi, Tana and Kiunga.

the Tana river, one of the two main Kenyan rivers. This transect provides the link with the land-based coral reef studies. The Kiunga transect is in the north of the country, in an unexplored area where the shelf is rather broad and where upwelling exists at times. At each transect three stations (with depths probably 100, 1000, 2000 m) will be studied. At each station a standard set of oceanographical parameters will be determined using the CTD/Rosette sampler with Niskin bottles at different depths. Light intensity, chlorophyll and oxygen measurements are necessary as well. It is proposed to attempt current measurements using profiling current meters and deploy floating sediment traps in a string down to 150 m deep.

Use will be made of meteorological observations. No wind measurements are made in Ungwana Bay and north of Lamu. It is proposed to install in addition to the two existing meteorological stations at Mombasa and Malindi two stations at Gazi and Kiunga with the aid of WMO/VAP (Voluntary Aid Programme). The state variables and the principal rates necessary to obtain an adequate and comprehensive picture of the pelagic system will be measured. This comprises nutrients, the microbial food web, phytoplankton and primary production, zooplankton and grazing.

The benthic systems will be studied by deploying box-corers, the NIOZ benthic lander and the benthic bottom profiler. Species composition and biomass of the benthos will be studied as well as sediment profiles, community respiration, fluxes of nutrients and other chemical components. The rate of sedimentation will be studied from ^{210}Pb measurements from cores.
The study must be supplemented with the relevant remote sensing data.

Hydrography and General features

The current systems on the Kenyan continental shelf completely reverse with the change in direction of the monsoon. Physical, chemical and biological processes will be strongly affected by these changes. The variability of the hydrographic features during the early stages of the two monsoon regimes will be studied. Specifically the project considers:
1) Temperature, salinity, density and oxygen concentration.
2) Current variability in response to wind changes.
3) Influence of the Tana plume on hydrography of the shelf.
The dispersal of suspended matter supplied by the river will be studied in both seasons, Turbidity and total concentration of suspended matter will be measured and the composition of the suspended matter will be determined by SEM Microprobe analysis.

Plankton

Primary production will be measured along the three transects. The growth limiting factor in both seasons will be studied. Nutrient availability will be assessed by nutrient uptake assays, including the measurement of nitrogen fixation. The physiology of the phytoplankton populations at different depths will be studied by measuring photosynthesis using both the oxygen technique and the ^{14}C technique. The distribution of ^{14}C and $^{35}S\text{-}SO_4$ in the different macromolecular pools will be followed in order to study C-turnover and net protein synthesis as a measure of growth. An estimate of the rate of new to regenerated production will be made using ^{15}N measurements.

Species composition, biomass and distribution of the phytoplankton will be investigated. The deeper benthic algal flora will be studied from box corers and underwater-TV on hard substrates. The importance of the microbial foodweb will be studied. Estimates of bacterial growth will be made in different water masses. The part of the primary produced material that will enter microbial populations directly, will be determined. The control of bacterial populations by heterotrophic nanoflagellates, protozoa and ciliates by grazing will be measured by direct counting and labelling of bacteria with a radioactive marker. Grazing on algae and how it determines phytoplankton population size and nutrient turnover will be estimated by determining the standing stock of zooplankton. Direct measurement of grazing is also envisaged. An inventory of dominant species will be made.

Benthos

The rate of sedimentation and deposition of organic material on the bottom will be studied by analysis of the benthic community (box-core, beam trawl), metabolic activity of the benthic system (bell-jar, bottom lander) with measurements of oxygen profiles in the sediments and nutrient exchange between bottom and water. For these experiments the benthic lander and the benthic bottom profiler will be used.

The structure of the benthic communities will be studied by determining biomass, densities and species composition of meio- and macrofauna. Major changes occur in the structural and functional attributes of shallow water marine environments between high and low latitudes. A prediction of the future consequences of global warming in particular climatic zones should be based on comparative studies so that these differences are properly documented and the mechanisms controlling them are understood.

The empirical evidence for diversity gradients in the marine environment is weak and contradictory. The classic paper of Sanders (1968) showed that within-habitat marine macrobenthic diversity for soft bottoms was higher in the tropics than in boreal regions. However, Thorson (1952) found that the number of infaunal species was roughly the same in arctic, temperate and tropical seas. Warwick and Ruswahyina (1987) could find no differences in macrobenthic diversity between sites in Java and the U.K.

On the meiobenthos there is no comparative information but since the mechanisms of diversity maintenance are probably different, a comparative study may provide a firm basis for mechanistic hypotheses. Comprehensive collections of benthos at different latitudes could also be used to examine hypotheses relating to other attributes of community organisation, specifically size and biomass spectra. For example the conservative bimodal pattern in temperate latitudes should be unimodal at high latitudes and strongly bimodal in the tropics.The biomass spectrum should be bimodal throughout the entire gradient.

The Community Ecology Group of the Plymouth Marine Laboratory has already collected strictly comparable data on community structure of the macrobenthos and the meiobenthos from representative sites in high latitudes, temperate and tropical zones and would welcome the opportunity to analyze material collected in the same way from the Kenyan shelf.

Past and present sediment distribution along the Kenyan coast

Sediments in the western Indian Ocean have been little studied. Preliminary investigations of the lithology and composition of the sediments are presented by the International Indian Ocean Expedition. A few samples taken along the shore off Somali and Kenya consist of calcareous sands. Recent work shows that after the last glacial period, precipitation in Eastern Africa was extremely high resulting in numerous floodings of the river Nile. The discharge of the river Nile was at that time so high, that a fresh-water layer developed in the Eastern Mediterranean. This caused water stratification, anoxic bottom water conditions and even deposition of organic rich layers (so called sapropels) in the Eastern Mediterranean.

The Tana and Sabaki rivers have been bringing sediments from the Kenyan Highlands towards the Indian Ocean for millions of years. The high precipitation after the last glacial in East Africa must have resulted in high discharges of these rivers to the sea. To document the higher discharge the sediments will be dated by oxygen isotope stratigraphy and ^{14}C AMS datings on forams. Cores with higher sedimentation rates will be studied in more detail (oxygen and carbon isotopes) to determine climatic changes in the recent geological past. The results will be compared with studies carried out on Mount Kenya, and with investigations on the erosion of volcanic minerals in the rift valley.

Finally the chemical composition of the sediments will be determined to quantify the relative contribution of lithogenous, biogenous, anthigenic, dissolution residue and hydrothermal phases to the chemical composition of the sediment. With these analyses origin and source of sediments can be determined.

Levels of potential pollutants in Kenyan waters

Marine pollution research and monitoring is a priority area in the KMFRI programmes necessary for pollution management and decision making. Until now pollution studies have been concentrated in the vicinity of Mombasa harbour and nearby creeks where oil spills have occurred and which are suspected to be contaminated by municipal sewage. The influx of fresh water into creeks around Mombasa island, particularly during the rainy season, has been shown to result in higher nutrient levels and probably also pesticide residues. The monsoon may therefore result in pulses of pollutants entering the ocean.

Although pollution studies are not part of the 'Tyro' programme samples will be collected to investigate the distribution and levels of hydrocarbon pollutants and trace (heavy) metals in the water and the sediments. The analysis will be done by the KMFRI scientists.

3.2. Kenyan coastal ecosystems and their interrelations.

(Project manager: M.A. Hemminga)

Going from the coast in a seaward direction, a number of characteristic ecosystems can be successively found along the Kenyan coast: a zone with mangroves is followed by a zone with seagrass vegetations in backreef lagoons; these lagoons are bordered by a belt of coral reefs; beyond the coral reefs the open ocean begins. In the ship-based research programme described above, the pelagic system of the open ocean water of the Kenyan shelf is the central issue. The coastal project presented here is complementary to this programme: research focus is on the adjacent mangrove, seagrass and coral reef systems. These marine ecosystems are connected by the tidal water which carries both abiotic and biotic elements to and from the systems. The relation between mangroves, seagrass beds and reefs (in terms of dissolved nutrients- and seston fluxes and shuttle movements of fish) is the central theme of the coastal project. Very little is known about the interlinkages between the coastal ecosystems in the East African region. However, information is indispensable for a rational management of the coastal ecosystems and their resources.

Attention will also be given to the emission of greenhouse gases by the mangrove sediments. Quantitative data on the emission of these gases by tropical wetlands are scarce, and more data are needed to improve the estimates for emission of greenhouse gases by natural wetlands on a global scale.
The coastal research programme will be carried out in Gazi Bay (see Figure A.5), about 50 km south of Mombasa. This site has the advantage of the presence of nearby laboratory facilities at the Kenya Marine and Fisheries Research Institute in Mombasa, and facilitates the participation of Kenyan scientists in the project. Furthermore, Gazi Bay is the location where a research project

focussing on the ecological functioning of mangroves currently is being carried out. This project is financially supported by the European Community (EC). Kenyan, Dutch and Belgian research parties participate. Concentrating the research work of both the European Community project and the coastal programme in Gazi Bay will be scientifically profitable, as the data resulting from the two projects

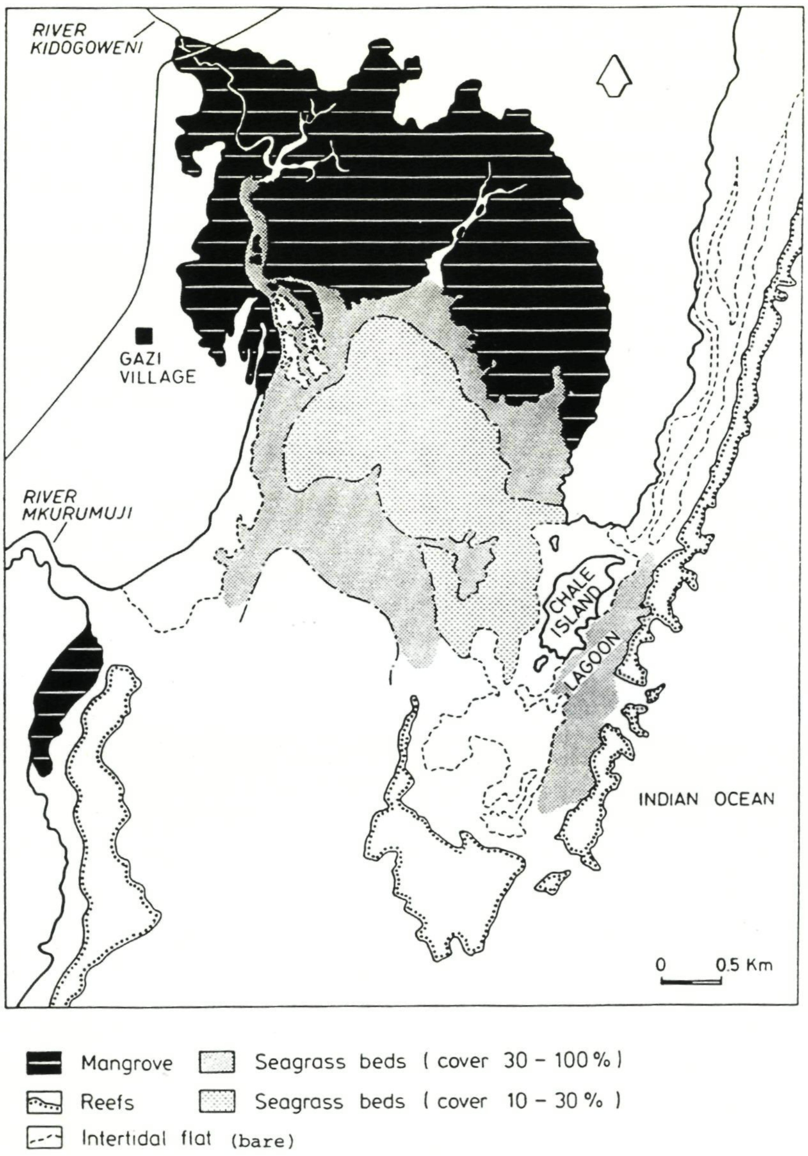


Figure A.5. Gazi Bay, the research area of the land-based programme.

can be connected to give a more thorough understanding of the functioning of a tropical coastal area. The integration of both projects, furthermore, will be advanced by the involvement of EC-scientists in some subprojects of the coastal programme. Moreover, one of the three transects of the ship-based research described in the previous section, is off Gazi Bay, giving the coastal programme a connection with the offshore research.

The coastal programme consists of four parts which are described separately below.

3.2.1 Isotope composition of mangroves and of seston in tidal currents between mangrove and ocean

(M. Hemminga (DIHO), J. Nieuwenhuize (DIHO), E. Slim (DIHO/ E.C.), A.F. Woitchik (VUB/E.C.)

To understand the influence of the Kenyan coastal ecosystems on each other, we propose to study the transfer of organic matter between systems with the stable carbon isotope technique. Stable isotopes are very useful for studies of ecosystems if there are two dominant isotopically distinct sources of carbon. Mangroves and seagrasses have ^{13}C-values of -27 and -10%, respectively, while the standard error in determining the ^{13}C-value is about 0.1-0.3%. It is also possible to use the isotope ratios in organisms to trace the origin of carbon actually assimilated into body tissues. They give no information on individual organisms consumed, but on the organic matter assimilated over several days, weeks or months. In determining the origin of animal organic matter, trophic levels must be taken into account: carbon isotope ratios of animals are an average of 1% more positive than that of their food.

During ebb and flood tides, outcoming and incoming water in mangroves, over seagrass vegetations and near coral reefs will be sampled and the seston in the water will be collected with a continuous centrifuge. In each system animals will be collected for the isotope studies. Bottom sediment samples in the coastal area surrounding the mangrove will be taken to assess the contribution of outwelling mangrove organic matter to sediment composition.

3.2.2. Seagrass meadows as nutrient and seston traps between mangrove and ocean.

(M. Hemminga (DIHO), E. Slim (DIHO/E.C), P. de Koeyer(DIHO), A.F. Woitchik (VUB/ E.C.), J. Kazungu (KMFRI) and J. Kinyamario (UoN))

Seagrass leaves are capable of capturing nutrients from the ambient water. In addition, the seagrass canopy tends to trap seston particles from the watercolumn. Leaf uptake and sedimentation probably are essential for the persistence of seagrass vegetations: a number of processes lead to nutrient losses from the seagrass beds (e.g., export of leaf material with currents, leaching processes, denitrification); obviously the continued existence of seagrass beds depends on mechanisms effecting a continuous replenishment of nutrients; uptake of nutrients by the leaves, and sedimentation, together with N_2-fixation, are responsible for counterbalancing these nutrient losses.

Their relative importance is unknown: combined measurements of these processes have not been carried out in any seagrass system. From an analysis of literature data, however, leaf uptake emerges as a proces of potentially major importance (Hemminga et al., 1991). The position of extensive seagrass vegetations between mangroves and coral reefs, and the processes associated with seagrass canopies mentioned above, imply that these systems may function as a trap which reduces the extent of the fluxes of seston and nutrients between mangrove and ocean. Such a phenomenon would be of considerable ecological interest.

The research concentrates on two questions:
1) *What is the relative importance of leaf uptake, sedimentation and N_2-fixation for nutrient input into the seagrass meadow of a backreef lagoon*?
The permanently submersed coastal plain in Gazi Bay between the mangroves and the coral reefs is dominated by dense stands of the seagrass *Thalassodendron ciliatum*, and the investigations will be carried out in plots of these vegetations. Leaf uptake will be measured in experimental chambers N_2-fixation will be determined using the acetylene-reduction technique. Measurement of N_2-fixation is an important component of the EC-mangrove project and will be in operation during the Kenya expedition. Sedimentation will be measured using coloured particulates applied in permanent plots. Cores of the marked sediments will be collected during the expedition and later on, by participants in the EC-project.

2) *Do seagrass meadows change the nutrient and seston content of tidal water flowing between mangrove and reefs*?
To answer this question, the tidal water mass flowing to or from the mangrove will be sampled and flow velocities will be measured when the tidal water passes the seagrass vegetations. Water samples will be taken on several depths, and analysed for particulate matter content and nutrient concentrations. Standing nets will be used to assess transport and catchment of larger (>1mm) particulate mangrove detritus. In addition, soil cores will be taken in the seagrass meadows, to investigate whether sediment composition shows gradients going from the mangrove side to the ocean (coral reef) side. Stable isotope techniques will be used to trace the origin of organic matter in the sediment (see also section 3.2.1.).

3.2.3. Importance of mangroves and seagrass beds for coral reef fishes.

(G. van der Velde (KUN), P.J.M. Bergers (KUN),P. van Avesaath (KUN), M. Versteeg (KUN), M.van Katwijk (KUN),J. Mutere (KMFRI), A. Melles (FAME, VUB), N. Kimani (KMFRI) N.J. Ntiba (UoN), M. Borel-Best (NNM; advisory participant)

Mangroves and seagrass beds are known to be nursery grounds or feeding areas of many fish species. Some species occur as juvenile and as adult in these biotopes but others are only present there as juveniles, while they are present as adults in other biotopes such as depth zones on the coral reef. Although seagrass beds and mangroves often occur in adjacent zones, their fish fauna is mainly studied separately. Studies in which fishes of coral reefs, seagrass beds and mangroves are studied together are very scarce. This is, in part, due to methodological problems. Several investigators indicated a positive influence of seagrass beds on the species composition and standing crop of the fish population on the coral reef. Also the mangroves can have such an influence on the occurrence of the coral reef fishes.

During a study of the Lac lagoon at Bonaire, where the fish community of adjacent mangroves, seagrass meadows and coral reefs was investigated, we developed a visual census technique, which seems satisfactory for the study of fishes which are easy to identify, not too shy and hiding. With drop nets day and night activity can be followed, while by means of these nets density and length estimations can be checked. With the drop net method also more complete fish lists can be obtained.

The field work in Gazi Bay will comprise several elements:
1. A description will be made of the structure of the coral reefs, by means of sampling, line transects and an echosounder.
(The structure of mangroves and seagrass meadows in Gazi Bay is studied within the framework of the EC-project; this information will be available)
2. Fishes will be caught in permanent plots over the gradient by means of drop nets to investigate the species composition, the length distribution of the various species and the densities over the various zones.
3. Fishes will be caught by means of drop nets during various times to study migratory movements and activity patterns during day and night (see also 2).
4. The various species of fishes will be counted by means of a visual census technique in permanent areas by two divers in the various zones. Their lenghts will be estimated.

3.2.4. Fluxes of gaseous C- and N-compounds to the atmosphere.

(Microbiologist (DIHO), J. Nieuwenhuize (DIHO), technician (DIHO)

Several gasses are released as the result of decomposition processes in tidal wetlands. Among these, CO_2, CH_4 and N_2O are greenhouse gases which are rapidly increasing in the atmosphere. N_2O is not only a greenhouse gas but it destroys the ozone layer as well. The sources and sinks of the above gases are reasonably known, but the individual contribution of each source to the global emissions can only be estimated. For instance the estimates for the emission of methane from natural wetlands vary almost an order of magnitude. The estimates can be improved by increasing the number of gas-flux measurements.
The research has two objectives:
1) To estimate the annual production of the above-mentioned gases.

2) To study the impact of short-term precipitation and inundation patterns on the release of CH_4, N_2O and CO_2.

In Gazi Bay a number of sites will be selected. During the expedition the release of gases will be intensively monitored to document the variation in gas fluxes due to flooding and precipitation. Gas-fluxes will be estimated using chambers connected to a gas-monitor. In addition soil salinity, nitrate concentration of the flooding water and organic carbon content of the soil will be determined.

4. Project Specifics

4.1. Participants and Classification

Project management:
Prof.dr. C. Heip & Dr. M.A. Hemminga
Delta Institute, Vierstraat 28,
4401 EA Yerseke (tel. +31-1131 1920)

Participating institutes and responsible scientists:
Delta Institute, Yerseke
M.A. Hemminga - seagrass studies, mangrove studies
E. Slim - mangrove studies
Microbiologist - geochemistry, mangrove studies
J. Kromkamp - primary production
N. Goosen - microbiology
Laboratory of Aquatic Ecology, Catholic University, Nijmegen
G. van der Velde - corals reef fishes
Netherlands Institute for Sea Research, Den Burg, Texel
W. Helder - marine chemistry
P.A.W.J. de Wilde - benthic metabolism
National Museum of Natural History, Leiden, The Netherlands
M.B. Best - stony corals (advisory participant)
Free University of Brussels, Belgium
L. Goeyens - pelagic system
A.F. Woitchik - mangrove and seagrass studies
A. Melles (FAME) - coral reefs ecosystem
Kenya Marine and Fisheries Research Institute, Mombasa, Kenya
J. Kazungu -
N. Kimani -
University of Nairobi, Kenya
J. Kinyamario -
N.J. Ntiba -
Plymouth Marine Laboratory, United Kingdom
R. Warwick - benthic system

Classification
Disciplines and subdisciplines:
marine ecology, biology, geology and chemistry
Areas of application:
fisheries; coastal zone management

4.2. Methods, Equipment and Facilities

The pelagic systems will be studied on each station by the following analyses and measurements:

- vertical distribution of nutrients, chlorophyll and oxygen
- photosynthetic measurements using the oxygen technique on concentrated samples and the ^{14}C technique.
- nutrient uptake measurements using concentrated samples of nitrogen, possibly phosphorus and iron. Also ^{14}C-methylammonium can be used as an ammonia analogue.
- nitrogen fixation measuring acetylene reduction by gas chromatography.
- measurement of new production by incorporation of ^{15}N-nitrate and ^{15}N-ammonium (planned)
- assimilation of $^{14}C\text{-}CO_2$ and $^{35}S\text{-}SO_4$ to determine C-turnover, carbohydrate to protein ratios and net protein synthesis during the photo- and scotophase.
- bacterial activity using ^{3}H-thymidine incorporation
- grazing of bacteria by protozoa, ciliates and heterotrophic flagellates by labeling bacteria
- estimates of population sizes of picoplankton, bacteria, ciliates and protozoa, phytoplankton, nanoflagellates and zooplankton
- grazing and vertical migration by zooplankton
- distribution of POM and DOM
- sedimentation by using sediment traps

The rate of sedimentation and deposition of organic material on the bottom will be studied by analysis of the benthic community (box core, beam trawl), metabolic activity of the benthic system (bell-jar, bottom lander) with measurements of oxygen profiles in the sediments and nutrient exchange between bottom and water. For these experiments the benthic lander and the benthic bottom profiler will be used.

The structure of the benthic communities will be studied by determining biomass, densities and species composition of meio- and macrofauna. In combination with the studies of the benthic system bottom sediment will be analysed for sediment structure as analysed by X-ray radiography and description of macroscopic features, layering, colour and texture. The sediments will be scanned for major elements. Grainsize of selected samples will be determined and particles identified by microscope (binocular and SEM). X-ray diffraction on selected samples will be carried out and the deposition rate of muddy deposits will be determined with ^{210}Pb and fall-out isotopes.

In the coastal programme various techniques will be applied. The stable isotope technique will be used to assess the significance of mangrove and seagrass material in the coastal foodweb (3.2.1.). Collection of the samples (seston, animals and plants) will be carried out during the expedition; seston samples will be collected with the use of a continuous centrifuge. The actual isotope analyses will be carried out in the Netherlands and Belgium. For the research on seagrasses (3.2.2.), samples of seagrass material and of undisturbed sediments from the seagrass meadows will be taken by scuba-divers. Nutrient uptake by the leaves will be determined experimentally with the use of incubation chambers kept in a temperature-controlled water bath. N_2-fixation will be determined using the acetylene-reduction technique. Nutrients in the water samples will be stored frozen and their concentrations will be determined after the programme with an auto-analyzer on board the Tyro, or in The Netherlands.

For the study on coral reef fishes (3.2.3.), a description will be made of the structure of the coral reefs, by means of sampling, line transects and an echosounder. Furthermore, fishes will be caught by means of drop nets to investigate species composition, length distribution, densities in the various zones and migratory movements. Fishes will also be counted by means of a visual census technique in permanent areas by two divers in the various zones. The fluxes of gaseous C- and N-compounds from the mangrove sediments (3.2.4.) will be measured by fastening polypropylene domes on the selected sites; these domes are connected to a gasanalyzer, which continually measures the levels of the various gasous compounds in the domes. In the sediment of the sites, salinity of the interstitial water and organic carbon content will be determined.

4.3. Training and Education

During the stay in Mombasa the Tyro will be at the disposal of the Kenyan scientific community for a four days training programme. The training programme will be developed by Kenyan and supported by Dutch and Belgian scientists.

5. References

Blom, J., van der Hagen, H., van Hove, E.M., van Katwijk, M.M., van Loon, R. & N.F. Meier, 1985. Decline of the Malindi-Watamu Reef complex. Quantitative and qualitative survey of the coral growth. Report no. 195, Lab. for Aquatic Ecology, KUN Nijmegen.

East African Meteorological Department, 1980. Climatological statistics for East Africa. Nairobi.

Giesen, W. & K. van de Kerkhof, 1984. The impact of river discharges on a Kenya coral reef ecosystems - the physical processes. Part 2: Effects on the Malindi-Watamu coastal environment. KUN Nijmegen.

Hemminga, M.A. & Harrison P.G. & van Lent, F. (1991) The balance of nutrient losses and gains in seagrass meadows. Mar. Ecol. Prog. Ser. 71:85-96

Katwijk, M.M. van, Meier, N.F., van Loon, R., van Hove, E.M., van der Velde, G. & C. den Hartog, 1989. River sediment load and coral response. Correlation between the increased sediment load from the Sabaki river and the condition of the Malindi-Watumu reef complex in Kenya. Coral Reefs.

Mantoura, R.F.C., J.-M. Martin, R. Wollast. 1991. Introduction. pp. 1-3. In: Ocean Margin Processes in Global Change. Report of the Dahlem Workshop on Ocean

Margin Processes in Global Change. Wiley Interscience, New York. 469 pp.
Pannikar, N.K., 1970. International Indian Ocean Expedition plankton atlas. Vol. II. Distribution of copepod and decapod larvae in the Indian Ocean. National Institute of Oceanography, India, 11 p.
McClanahan, T.R. 1988. Seasonality in East Africa's coastal waters. Marine Ecology Progress Series 44: 191-199
Warwick, R.M. & I. Ruswahyuni, 1987. Comparative study of the structure of some tropical and temperate marine soft-bottom macrobenthic communities. Mar. Biol. 95: 641-649.
Sanders, H.L. 1968. Marine Benthic Diversity: a comparative study. American Naturalist 102:243-282.
Tana River Development Authority, 1981. Athi River pre-investment study. Annexes 1-11. Nairobi.
Thorson, G. Zur jetzigen Lage der marinen Bodentier-Okologie. Zool.Anz (suppl) 16, 276-327.

Remark: The figures in this chapter are redrawn after McClanahan, 1988


GO
GO

B

Monsoons and Pelagic Systems

1. Introduction

Among the oceans the Indian Ocean is unique because, by the alternation of the NE monsoon in winter and the SW monsoon in summer, the surface circulation in the northern part reverses every half year. In the summer season strong upwelling occurs along the Somalia coast (Warren et al., 1966) and the coast of the Arabian peninsula (Currie et al., 1973). Weaker upwelling is observed along the southwest coast of India in the beginning of the summer (Sharma, 1978). In late summer, upsloping of cool water onto the shelf and subsequent winter convection may give enrichment along the coast of Pakistan (Banse, 1984). In the NE monsoon, heavy river runoff enhances production in this area (Banse & McClain, 1986). Also in the NE monsoon, slight upwelling has been reported from northern Kenya, when the Somali Counter Current and the South Equatorial Current leave the coast, turn east and form the Equatorial Counter Current (Kabanova, 1968, see McClanahan, 1988). The South Equatorial Current at about 10°S isolates the northern Indian Ocean, its surface water therefore has a relatively long residence time, also because of the clockwise and anticlockwise directed gyres. The flow in the intermediate layers is not well known but may reverse as well (Wyrtki, 1971) and lacks transequatorial water transport (Sharma, 1976). Abyssal circulation is restricted as the Carlsberg Ridge reduces the flow of bottom water from the Somali Basin into the Arabian Basin.

The combination of various upwellings with a reduced water exchange at all depth levels leads to an exceptionally severe and persistent oxygen minimum in the intermediate layers of the NW Indian Ocean (Slater & Kroopnick, 1984). In the northern Arabian Sea, downstream of the Somali and Arabian upwelling, the decay of organic material below the photic zone lowers oxygen concentration to under 0.2 ml/l at a depth of 600 m (Wyrtki, 1971). At the shelves and slopes in this area, with depths within the range of 150-1500 m of the oxygen minimum layer, surface sediments are rich in organic carbon due to a decreased aerobic mineralization (Kolla et al., 1981).

An oxygen minimum layer is also a dominant feature in the Red Sea, the geologically recent basin connected via the strait of Bab-el-Mandab with the NW Indian Ocean. By the very shallow sill depth of only 100 m, no cold, deep water of the Indian Ocean enters. Consequently, the deep waters (up to more than 2000 m) of the Red Sea have an exceptional high temperature, of above 20°C. Salinity is high as well, due to excess evaporation, and is around 40 promille at the surface and at depth. In the summer season, the wind driven surface current in Bab-el-Mandab is directed to the Indian Ocean, but in winter this Gulf of Aden current has reversed. Below the upper 40-50 m, one or more counter currents may occur. Especially at the end of the summer, there is a net flow of nitrate-rich subsurface water (50-100 m) into the Red Sea (Poisson et al., 1984).

For this oceanographic area with extreme changes in the surface layer (both in space and in time) and with a persistent oxygen minimum layer at intermediate depth, the present study is designed to describe two topics:

a)the carbon flux in the pelagic system, i.e. production, consumption/ mineralization and sedimentation down to a depth of ca. 2000 m, according to JGOFS protocols (see below), and

b)vertical and horizontal distribution of upwelling species and of oligotrophic species of plankton and micronekton, and their metabolic activity and life strategy in relation to hydrographic conditions.

1.1.International Context

Contact has been made with the SCOR International Committee for Joint Global Ocean Flux Study (JGOFS) concerning the Carbon fluxes in the pelagic system. The JGOFS scientific strategy is based on two main goals; 1) to determine and understand on a global scale the processes controlling the time-varying fluxes of carbon and associated biogenic elements in the ocean, and to evaluate the related exchanges with the atmosphere, sea floor and continental boundaries, and 2) to develop a capability to predict on a global scale the response of oceanic biogeochemical processes to anthropogenic pertubations, in particular those related to climate change. NW Indian Ocean is among the key areas of JGOFS, the others being the North Atlantic, the Southern Ocean (Antarctic) and the Equatorial Pacific. JGOFS Indian Ocean is formally planned for 1994/1995, but the larger part of the Netherlands Indian Ocean Programme 1992/ 1993 is regarded to fit well into the JGOFS goals, so data will be collected conform JGOFS protocols and will form the starting point of the JGOFS Indian Ocean Date Base. Especially the studies in the upwelling zone of Somalia (Projects B and C) will cover nearly all 20 JGOFS core measurements.

The biogeography part of the programme is associated with the SCOR Working Group on Pelagic Biogeography. As stated in the terms of reference of the working group the emphasis is on studying the mechanisms of distribution, not only the patterns, and therefore there are strong connections with ecological research. In the present project, especially the interaction between organisms and their physical-chemical-biological environment will be studied using new approaches (metabolic activities, specific enzymes, schooling and migratory behaviour). Through the multidisciplinary approach, there will be a multitude of background information available in the form of precise profiles of temperature, salinity, oxygen, macro- and micronutrients, bacteria, phytoplankton and primary production. This will enable a thorough and an as complete as possible study of the pelagic populations and the factors influencing their horizontal and vertical distribution patterns.

2. Scientific Rationale

Below, we firstly give a short overview of the existing knowledge on productivity and important consumers in the pelagic food web of the NW Indian Ocean, and subsequently we will list a series of specific questions.

2.1. Plankton Dynamics

The warmer and more saline waters of the Red Sea are fatal for many plankton species of the Indian Ocean. In the inflowing water, mass mortalities of pteropods occur, their shells form an ooze at the northern side of the sill (Stubbing, 1939). The Red Sea has a relative paucity in plankton species compared with the Indian Ocean, and a number of the species present might be endemic (Halim, 1969). Seasonality and productivity are poorly studied in the Red Sea but indicate a pattern inverse to that of the NW Indian Ocean. Probably due to the subsurface inflow of nutrient-rich water at the beginning of the NE monsoon, more plankton occurs in winter than in summer (Halim, 1969). Chlorophyll concentrations in winter are above 60 mg/m^2, about twice the values recorded in the NW Indian Ocean in that season. In summer, during the SW monsoon, the chlorophyll concentration in the Red Sea is generally below 30 mg/m^2 whereas in large parts of the NW Indian Ocean values reach 50-300 mg/m^2 due to upwelling.

Since the International Indian Ocean Expedition (IIOE, 1959-1965), abundance and species composition of plankton in the upper 200 m of the NW Indian Ocean are fairly well described. Atlasses, symposium proceedings and reviews regarding the biological results of the IIOE include a.o. Wyrtki (1971), Zeitzschel (1973), Krey & Babenerd (1976), NIO (1977), Rao (1979), Angel (1984), Haq & Milliman (1984). During the IIOE mainly tank incubations were done to measure the potential primary production. By application of the light profile a.o. (McGill, 1973), the in situ production was estimated. Remarkably, results presented differ markedly between authors. In Krey (1973) the in situ primary production is above 0.5 $gC/m^2.d$ in the whole NW Indian Ocean both during the SW and the NE monsoon. Kabanova (1968, see Cushing, 1973) reached > 1.0 $gC/m^2.d$ for the western area of the Arabian Sea in the SW monsoon, and only < 0.3 $gC/m^2.d$ in the NE monsoon (implying an annual production of about 250 gC/m^2). Later work in the Somali upwelling confirms the difference in primary productivity between seasons: 1.7 in and 0.7 outside the upwelling areas in July 1979, and 0.3 $gC/m^2.d$ in the NE monsoon, March 1979 (Smith & Codispoti, 1980). Productivity measurements by the same group of scientists denote that the latter value is not much higher than those for the Sargasso Sea off

Bermuda, and that the upwelling figures are comparable with those from the Peru upwelling (Smith, 1984). The dominating diatom is the same as near Peru, *Nitzschia delicatissima*, and the dominating grazer is the same as in the W-African upwelling, the copepod *Calanoides carinatus* (Smith, 1982). In some aspects the Somali upwelling is different. In Peru and W-Africa, a complex system of currents and processes traps the nutrients and the plankton populations in the upwelling area (Packard et al., 1984), but it is questionable whether this holds for Somalia. Upwelling plumes at 5° and 10°N comprise areas much larger than Peru and W-Africa (Smith, 1984) and upwelling is not of the Ekman-type but because of the strong Somali Current flowing along the coast turns to the east. The upwelled water flows towards the open NW Indian Ocean, and cores can be followed for long periods, sometimes as far as the coasts of Pakistan and India (Düing et al., 1980). The enrichment thus spreads over a very large area and, in combination with the upwelling along the Arabian coast, results in a phytoplankton biomass in almost the whole NW Indian Ocean more than twice as high as in the oligotrophic NE monsoon (Krey, 1973).

The differences in zooplankton and nekton stocks between the monsoons are less clear and less understood. Pooled data on displacement volume of zooplankton catches during IIOE show highest values in the NW Indian Ocean (Rao, 1973), but there is a shortage of observations in the NE monsoon, especially in the offshore regions (Cushing, 1973). Large populations of anchovy, sardine and other fishes known for upwelling areas, are lacking in the Somali current system, probably because there is essentially no shelf and because upwelling is limited to half of the year. Most of the productivity seems to be channelled via copepods to the mesopelagic lanternfishes, the Myctophidae. Acoustic surveys in combination with pelagic trawling in the period 1975-1983 revealed dense populations of these fishes at relatively shallow depths (< 250 m). In the Gulf of Oman high catch rates were obtained (Gjsæter, 1984). *Benthosema pterotum* (4 cm), most abundant in that area, has a fast growth rate and spawns and dies after 6 months. Seasonal cycles in these fishes in relation to upwelling are not clear, probably because the Oman upwelling may be still very strong in October-November (Ryther & Menzel, 1965), whereas subsequently winter blooms may occur (Banse & McClain, 1986). The extensive oxygen minimum zone in the NW Indian Ocean could well play an important role why such a large part of the total biological production is channelled through the mesopelagic fishes (Gjsæter, 1984).

2.2. Specific Questions

From the papers and reviews cited above, it is clear that since the IIOE in the sixties, the basic oceanographic knowledge of the NW Indian Ocean is considerable, though a large number of gaps can be recognized (Angel, 1984). In addition, major improvements in sampling techniques have occurred since IIOE, so we intend to study the ecosystem dynamics of one or two major upwelling areas in more detail, both in the SW monsoon and in the NE monsoon. As far as we are aware, this has only been done once since IIOE, by the RV Columbus Iselin in 1979 (the US Indian Ocean Experiment, INDEX). Other recent cruises in the NW Indian Ocean were in only one of the two monsoons or in the transition periods.

Present descriptions are more detailed for the Somali current upwelling than for the Yemen/Oman upwelling. The data suggest a persistent summer upwelling at 10°N, with the almost certain presence of diatom and copepod upwelling species. However, it can be expected that a very identical ecosystem occurs in the Oman upwelling. Instead of time-consuming mapping of the upwelling plumes (Smith & Codispoti, 1980; Smith, 1982), we prefer to study carbon fluxes at (drogue) stations in a limited area in more detail. Compared with IIOE and INDEX we will not limit the zooplankton/micronekton sampling to the upper 200 m, but will include the mesopelagic fauna, down to 2000 m. Areas bordering and under the influence of the upwelling zones will be visited as well, including the Red Sea (Figure B.1). If the site of the upwelling station will be off Oman, the position of the other stations will probably not differ essentially.

The research plan comprises two main themes: a carbon flux study to quantify production/mineralization, and a biogeographical study to trace the effect of seasonal upwelling on epi- and mesopelagic species composition, distribution and life strategies. At the stations outside the upwelling area measurements on production/mineralization will be done also, and in the upwelling area the planned midwater trawl-programme down to 2000 m will be performed as well. Full integration of both parts of the project will further be reached by doing metabolic measurements on biogeographically interesting species.

The carbon flux part of the project will cover most of the core measurements currently incorporated in the programme of the Joint Global Ocean Flux Study. After the 1989/1990 pilot cruises in the North Atlantic, it is planned that JGOFS efforts in subsequent years will include the NW Indian Ocean as well (cf. Smith, 1990). Most of the participating scientists so far listed for different items, were involved in the Indonesian-Dutch Snellius II Expedition 1984/1985. We will refer to their (or their colleagues) work in Indonesia when treating some of the following basic questions.

Although biological oceanography plays a major role in the current proposal, a number of physical and chemical variables will be measured at each station. Profiles down to 2000 m will be collected for temperature, salinity, oxygen, nitrate, nitrite, ammonium and silicate. Special attention will be paid to the accurate determination of the concentration of carbon dioxide and of dissolved organic carbon. DOC is a key variable in the carbon dynamics of the ocean

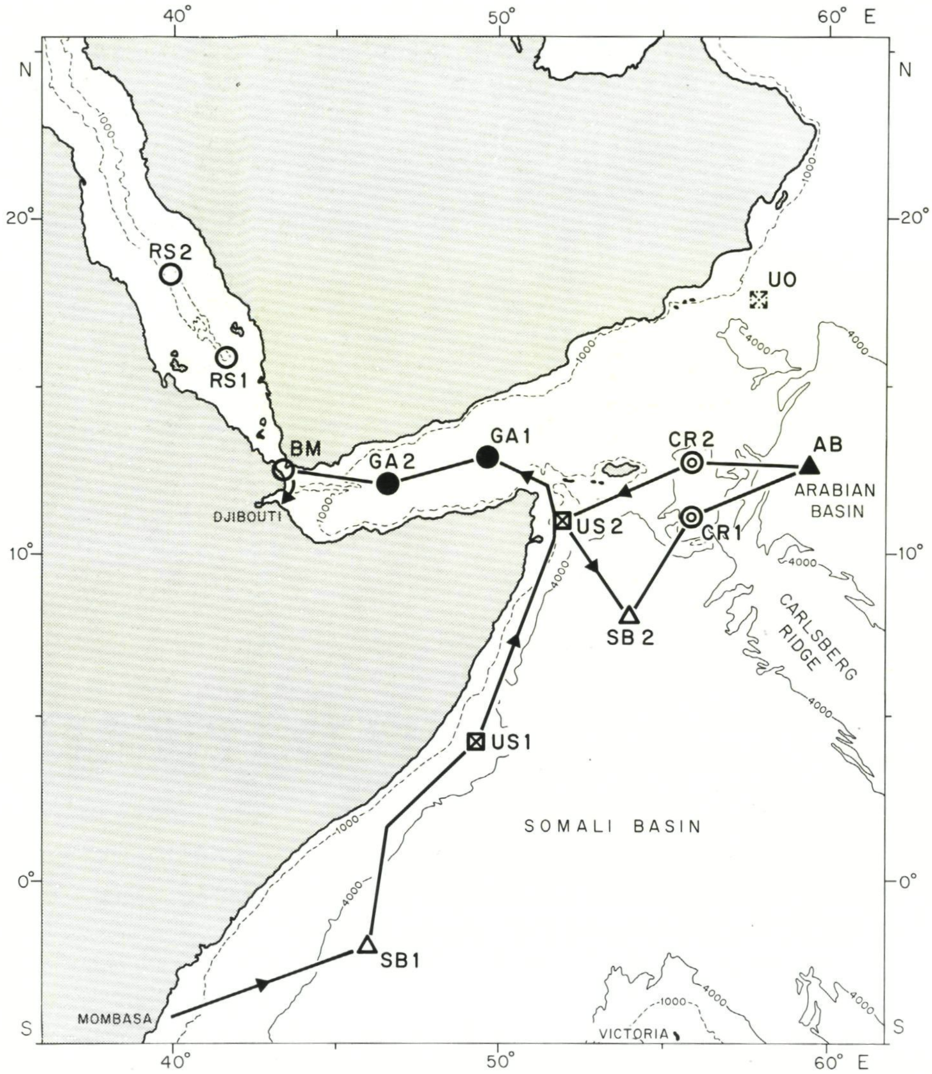


Figure B.1. Cruise track planned for July/August 1992 during the SW monsoon. Symbols and codes depict stations in different areas: upwelling sites near Somalia (US), cold rings (CR) in the area downstream, locations in the Somali Basin (SB) and in the Arabian Basin (AB), and in the Gulf of Aden (GA) including Strait Bab-el-Mandeb (BM). If upwelling along the Arabian Peninsula is studied, an area near Oman (UO) will be visited and the positions of the other stations adapted. The cruise track for January/ February 1993 during the NE monsoon will be very similar, except that southern stations will shift eastwards as sailing starts in Victoria (Seychelles). The stations in the Red Sea (RS) will be visited during this cruise as well as during the outward voyage (May/June 1992).

and therefore of importance for understanding the capacity of the oceans to store CO_2, the gas which is predominantly responsible for the present increase of the greenhouse effect. Also, concentration and dynamics of N_2O, another gas involved in the greenhouse effect, will be studied. Currently, the NW Indian Ocean is believed to produce a substantial part of the global N_2O production.

What is the primary production in both seasons? Recent work with the ^{14}C and the oxygen method in an area with relatively weak seasonal upwelling, the eastern Banda Sea, revealed an annual productivity of 500 gC/m^2 (Gieskes et al., 1990; Tijssen et al., 1990), twice the amount for the strong Somali upwelling (see above). Is this discrepancy solely due to differences in methodology or are variables in the field very different between these areas? Present arrangements within ICES and JGOFS for standardization of the ^{14}C method seem promising to solve part of this question.

How do sizes, group and species composition, and carbon biomass of phytoplankton vary seasonally? Virtually nothing is known about these aspects since nuclepore filters, HPLC, flow cytometry etc. were unknown at the time of the IIOE. Conversion of chlorophyll into phytocarbon may require much higher C:chl ratios (> 100) for tropical upwelling regions than those applied in temperate waters, as suggested by work with the Redalje/Laws method in the Banda Sea upwelling (Gieskes & Kraay, 1989).

What part of the production goes to the microbial loop? Since the last decade, the picture has arisen that also in tropical systems most of the daily production is consumed by the microbial loop (cf. Longhurst & Pauly, 1987). Experiments on incorporation of 3H-thymidine should provide estimates of bacterial activity. In addition to enumeration by epifluorescence microscopy, we will try in the present project to apply shipboard flow cytometry to quantify bacteria, heterotrophic flagellates and naked ciliates separately. Incubations are planned to determine the grazing rate of microzooplankton on bacteria (by techniques based on selective chemical inhibition) and on phytoplankton (by dilution series). Also, the usually neglected but often numerous metazoan component of the microzooplankton (the nauplii and young copepodites of small copepod species) will be sampled, by using 50 mm vertical nets in addition to the 200 or 300 mm mesh sizes used in the past.

Is the rate of sedimentation into the oxygen minimum layer related to the type of prey and the type of grazers? In tropical upwelling conditions a substantial part of the diatom blooms may be consumed by copepods, euphausids or herbivorous fishes (Smith, 1984). In the Banda Sea upwelling, ambient phaeopigment concentrations were high (Arinardi et al., 1990), but free drifting sediment traps at a depth of 100 m indicated that only 5% of primary production sunk out of the photic zone (Cadée, 1988). This suggests a considerable degree of coprophagy and it is worthwhile to study this in the Somali upwelling by deck incubations. Such experiments for separate species will also facilitate comparisons of abundance and type of pellets between different depths. Due to the pronounced oxygen minimum layer, it can be expected that mineralization of particles below the photic zone is slow, and that in such conditions a relatively large part of the primary productivity may be lost to depth (Smith, 1990).

Do secondary and tertiary production vary seasonally? Growth measurements for tropical consumers are rare as proper distinguishment between juvenile stages is very difficult because of lack of taxonomic descriptions and because of species richness. Earlier attempts to calculate secondary and tertiary production in the

Indian Ocean were not based on direct measurements but on general ecological efficiencies or on data for temperate species (Cushing, 1973). In *Calanoides carinatus*, growth rates of nauplii and early copepodids will be determined from molting rates of single stages. We intend to compare that laborious incubation method with the RNA/DNA method (cf. Båmstedt & Skjoldal, 1980). The RNA/DNA ratio as index for growth rate will be determined in many other zooplankton species as well. Species will be measured also for respiration (ETS method), and egg production in deck incubations. In a number of groups, typical upwelling species will be compared with oligotrophic species. A preliminary selection for copepods comprises: *Calanoides carinatus*, *Rhincalanus nasutus*, *Clausocalanus furcatus*, *Eucalanus crassus* and *Euchaeta marina* versus *Acartia negligens*, *Cosmocalanus darwinii*, *Undinula vulgaris*, *Eucalanus attenuatus* and *Pleuromamma indica*.

For the biogeographical part of the project the topics are mostly related to the lack of data on pelagic organisms below 200 m. The following questions will be addressed:

How does the upwelling influence the exchange between populations in the Indian Ocean and the Red Sea? Upwelling may act as a barrier for oligotrophic species (Fleminger, 1986). The pteropod *Clio pyramidata* is known only from stratified waters, whereas *Clio convexa* can be found also in mixed waters. Both do occur in the Indian Ocean, but only *Clio convexa* has been found in the Red Sea (cf. van der Spoel, 1973). Is their occurrence in the Somali upwelling in line with the hypothesis, i.e. is *Clio convexa* present and *Clio pyramidata* absent? Closer examination of single species in the Atlantic and Mediterranean revealed in pteropods and mesopelagic fishes a marked polymorphism (Furnestin, 1979; Badcock, 1981; Hilgersom & van der Spoel, 1987) or even necessitated the splitting in several species (Gibbs, 1986). Are such morphs also existing for species inhabiting the open Indian Ocean, the Somali upwelling and the Red Sea? Do vast oxygen minimum layers isolate populations in neighbouring oxygenated areas, thereby facilitating speciation (cf. White, 1988)?

Are species from the Atlantic and the Pacific Oceans really missing in the Indian Ocean? The mere lack of catches below 200 m in the Indian Ocean invalidates the disjunct distribution of many mesopelagic species presented in the literature. On the other hand, reports on the occurrence of species for Atlantic and Indian Oceans but missing in the Pacific, might be untrue also. Closer taxonomical examination of undamaged and well- preserved specimens may reveal that separate species for Atlantic and for Indian Ocean/Red Sea may be involved, as demonstrated for the pteropod *Diacria crassa* (van der Spoel, 1976).

Where do upwelling species occur during the NE monsoon? It is virtually unknown where the winter populations of upwelling species such as the copepods *Calanoides carinatus* and *Rhincalanus nasutus* can be found. Some data on catches below 1000 m do not list these species (Grice & Hulsemann, 1967), and from observations in upwelling areas elsewhere, it is to be expected that the pre-adult stage is resting at intermediate depths, between 200 and 1000 m. Weikert (1980) describes such a population of *Rhincalanus nasutus* at ca. 500 m in the oxygen minimum layer of the Red Sea. Do they spend their diapause in this layer in order to minimize predation? In what time of the year do the Red Sea copepods reproduce in the photic zone? Or is this deep population of *Rhincalanus nasutus* trapped in the Red Sea after immigration via the Bab-el- Mandab undercurrent at the end of the upwelling season? Once deep populations are located, specimens will be examined on lipid stores and gonad development, and individuals will be grown in cultures in an attempt to induce egg production.

Which type of deep scattering layers (DSL's) can be found in the NW Indian Ocean? Very few observations on DSL's have been published for the Indian Ocean. In the equatorial part, acoustic recordings by 38 kHz echosounding showed the diel migrating DSL (Bradbury, 1971) but not the DSL permanently at 400-500 m both day and night, as known from the Atlantic and Pacific Oceans. A similar lack of the permanent DSL was recently observed in the Banda Sea (Schalk et al., 1990). Fishes responsible for this type of DSL include the group of cyclothones, and in the Banda Sea these occurred much more shallow than usual, in probable relation to abnormal temperatures at depth (van der Spoel & Schalk, 1988). Such deviating patterns can be expected as well in the Red Sea (for which we could not trace any literature on DSL's at all) because of the very high temperature at depth and because of the oxygen minimum layer. The latter variable may predominantly influence the depth distribution of mesopelagic fishes in the NW Indian Ocean (cf. Gjsæter, 1984).

Is there an inverse relation between upwelling and neuston abundance? Our work in the Banda Sea suggests that the open-ocean species *Halobates germanus* and *Halobates micans* are much less abundant in the upwelling season than in the oligotrophic season (Cheng et al., 1990). Both species do occur in the NW Indian Ocean according to fragmentary data, so we like to verify the Banda Sea results in the Somali or Oman upwelling region. It might be very rewarding to extend such a study to other species in the neuston, also in search of which oligotrophic medusae or crustaceans may possibly form favourite prey species for the seaskater *Halobates*.

3. Project Specifics

3.1 Participants and Classification

Project management:

Dr. M.A. Baars
Netherlands Institute of Sea Research
P.O. Box 59, 1790 AB Den Burg, Texel
Tel. (+31) (0)2220-69511
Telefax (+31)(0)2220-19674

Prof.Dr. S. van der Spoel
Institute of Taxonomic Zoology
(University of Amsterdam)
P.O. Box 4766, 1009 AT Amsterdam
Tel.(31) (0)20-5257234

Participating institutes and responsible scientists:

Netherlands Institute of Sea Research (Texel)
Dr. M.J.W. Veldhuis - phytoplankton
Dr. M.A. Baars - ecosystem dynamics

Institute of Taxonomic Zoology (University of Amsterdam)
Dr. P.H. Schalk - macrozooplankton
Prof.Dr. S. van der Spoel - pelagic biogeography

Laboratory of Ecology & Systematics (Free University, Brussels, Belgium)
Dr. M.H. Daro - zooplankton

Oceanographic & Atmospheric Sciences Division (Brookhaven National Laboratory, Long Island, USA)
Dr. S.L. Smith - zooplankton

Graduate Programme Marine Biology (Higher Education Consortium, Charleston, USA)
Prof.Dr. R.K. Johnson - micronekton

Currently, participation is extended to the following scientists:

Institut für Meereskunde (Universität Kiel, Germany)
Prof.Dr. B. Zeitzschel/Dr. F. Pollehne - sedimentation

Plymouth Marine Laboratory (NERC, UK)
Dr. N.J.P. Owens - new production and N_2O formation
Dr. P.H. Burkill - microzooplankton

National Institute of Oceanography (Goa, India)
Dr. B.A. Biddanda - microbiology

Also, collaboration on the processing of samples (without their actual participation in the cruises) is envisioned with:

Scripps Institution of Oceanography (University of California, San Diego, USA)
Dr. L. Cheng - *Halobates*

Rani Durgavati University (Jabalpur, India)
Dr. S.C. Pathak - insects at sea

University Kebangsaan Malaysia (Bargi, Selangor, Malaysia)
Dr. B.H.R. Othman - copepods

Classification
Disciplines and subdisciplines:
biological oceanography (pelagic production cycle; pelagic biogeography)
Areas of application:
climatology (greenhouse effect) fish stock assessment

3.2. Area

Within the series of Dutch cruises in the Indian Ocean the project on seasonal upwelling is most rewarding in the areas covered by the stations depicted in Figure B.1. The upwelling near India, Pakistan or Kenya is weaker and not well understood. In such areas the project would run a high risk of encountering non-representative conditions. Upwelling stations involve one or two areas, located near Somalia at 10°N and 5°N. Downstream of the Somali upwelling area, stations in cold rings are scheduled. Additional stations are located above the Somali Basin, above the Arabian Basin, in the Gulf of Aden and in the Red Sea. If feasible, a limited sampling programme in Strait Bab-el-Mandeb will be attempted. All stations involve only water and plankton sampling. In Project B there will be no coring or other types of bottom surveys.

3.3. Schedule

The following cruise periods and stations are provisionally scheduled:
Part of outward voyage. During sailing from Port Said to Mombasa, in May/June '92, stations are planned in the Red Sea plus some additional work in Strait Bab-el-Mandeb and near Somalia.
Cruise in the SW monsoon. The track in the upwelling season comprises 28 days in total, and is programmed to start in Mombasa and to end in Djibouti, during July/August. The cruise covers 7 sampling days at stations visited for about 24 hours, and about a similar effort in 2 or 3 centres of upwelling. If time permits, some sampling in Strait Bab-el-Mandeb is envisioned, but the Red Sea stations will not be visited during this cruise period.
Cruise in the NE monsoon. The cruise in the oligotrophic season lasts 26 days in January/February 1993. Planned to start in Victoria and to finish the stations east of 50°E. Thereafter the stations in the Gulf of Aden and in the Red Sea are scheduled, each lasting about 24 hours. The cruise ends at Djibouti.

3.4. Methods, Equipment and Facilities

A wide variety of sampling and processing methods has been indicated in section 2.2. Sampling sequence at standard stations will basically be arranged according to the diurnal pattern, with water sampling early in the morning and in the evening, comprising oceanographic casts down to 1000-2000 m and special casts for production and mineralization down to 300 m. Sampling in the oxygen minimum and in the chlorophyll maximum will be facilitated by the in situ oxygen probe and fluorometer mounted on the CTD-rosette sampler system. At sunrise, a buoy-drogue system with production bottles and sediment traps is launched. A radio transmitter attached to the buoy enables tracking of direction and velocity of the surface current, and retrieval of the buoy after 24 hours the next morning. To facilitate the estimates of primary production, measurements of the underwater spectral irradiance will be performed each day around noon. Plankton sampling will be done along various ways. Animals for life experiments and biochemical measurements are mainly collected by vertical net hauls in the upper 200 m, at the beginning both of the day and of the night period. Bulk sampling for biomass and taxonomic analysis of meso- and macroplankton will be by a Rectangular Midwater Trawl 1+8, which acoustically opens and closes at depth. Series by day and at night are planned for the strata 0-100, 100-200, 200-300, 300-400, 400-500, 500-1000 and, occasionally, 1000-2000. During the night hauls by the RMT 1+8, a David-Hempel neuston net shall be employed simultaneously. Double oblique hauls with an in situ zooplankton counting tube, mounted in a Gulf high-speed plankton sampler, are planned to obtain a more detailed picture of the vertical distribution and to locate deep populations of animals in diapause near or in the oxygen minimum layer. Deep scattering layers will be traced by a 30 kHz sounder onboard RV Tyro. Shipboard equipment involves predominantly a variety of deck incubators and filtration set-ups, for measurements on production, mineralization, grazing, egg production, etc. A pump system provides continuously information on temperature, salinity, oxygen and chlorophyll fluorescence of the upper part of the mixed layer. A total of about 17 containers will be in use during the cruises of the present programme, including 5 general laboratories, 2 laboratories for work with radioactive tracers, a flowcytometer laboratory, 2 laboratories for nutrient analyses and 2 climate rooms for work at low temperatures. Facilities are planned for onboard receival and processing of satellite images on temperature and chlorophyll.

3.5. Training and Education

One of the present participants (Dr. M.H. Daro) is involved in the Kenya-Belgium Project in Marine Sciences, at the Kenya Marine and Fisheries Research Institute, Mombasa. This project will be widened towards a regional co-operation in scientific information exchange (UNESCO, 1988), but currently also comprises the planning of international training courses in marine sciences. Young scientists from a number of countries will be invited, including Somalia, Djibouti and Ethiopia, countries bordering the proposed study area. It is hoped for that these contacts will facilitate TEMA activities (Training, Education and Mutual Assistance) during and after the cruises.

4. References

Angel, M.V., 1984. Deep-water biological processes in the northwest region of the Indian Ocean. Deep-Sea Res. 31: 935-950.

Angel, M.V. (Ed.), 1984. Marine science of the north-west Indian Ocean and adjacent waters. Proceedings of the Mabahiss/John Murray International Symposium, Egypt,3-6 September 1983. Deep-Sea Res. 31: 573-1035.

Arinardi, O.H., M.A. Baars & S.S.. Oosterhuis, 1990. Grazing in tropical copepods, measured by gut fluorescence, in relation to seasonal upwelling in the Banda Sea (Indonesia). - Neth. J. Sea Res. 25: 545-560.

Badcock, J., 1981. The significance of meristic variation in *Benthosema glaciale* (Pisces, Myctophidae) and of the species distribution off northwest Africa. Deep-Sea Res. 28: 1477-1491.

Båmstedt, U. & H.R. Skjoldal, 1980. RNA concentration of zooplankton: relationship with size and growth. Limnol. Oceanogr. 25: 304-316.

Banse, K., 1984. Overview of the hydrography and associated biological phenomena in the Arabian Sea, off Pakistan. In: B.U. Haq & J.D. Milliman (Eds.). Marine geology and oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, New York, 271-303.

Banse, K. & C. McClain, 1986. Winter blooms of phytoplankton in the Arabian Sea as observed by the coastal zone colour scanner. Mar. Ecol. Prog. Ser. 34: 201-211.

Bradbury, M.G., 1971. Studies on the fauna associated with the deep scattering layers in the equatorial Indian Ocean during October and November 1964. In: G.B. Farquhar (Ed.). Biological sound scattering in the ocean. Office of Naval Research, Washington, D.C.: 409-447.

Cadée, G.C., 1988. Organic carbon in the upper 100 m and downward flux in the Banda Sea; monsoonal differences. Neth. J. Sea Res. 22: 109-121.

Cheng, L., M.A. Baars & S.S. Oosterhuis, 1990. *Halobates* in the Banda Sea (Indonesia): monsoonal differences in abundance and species composition.- Bull. mar. Sci. 47: 421-430.

Cushing, D.H., 1973. Production in the Indian Ocean and the transfer from the primary to the secondary level. In: B. Zeitzschel (Ed.). The biology of the Indian Ocean. Springer, Berlin, 475-486.

Currie, R.I., A.E. Fisher & P.M. Hargreaves, 1973. Arabian Sea upwelling. In: B. Zeitzschel (Ed.). The biology of the Indian Ocean. Springer, Berlin: 31-52.

Düing, W.O., R.L. Molinari & J.C. Swallow, 1980. Somali Current: evolution of surface flow. Science 209: 588-590.

Fleminger, A., 1986. The pleistocene equatorial barrier between the Indian and Pacific Oceans and a likely cause for Wallaces line. Unesco tech. pap. mar. sci. 49: 84-97.

Furnestin, M.-L., 1979. Aspects of the zoogeography of the Mediterranean plankton. In: S. van der Spoel & A. Pierrot-Bults (Eds.). Zoogeography and diversity in plankton. Bunge, Utrecht: 191-253.

Gibbs, R.H., 1986. The stomioid fish genus *Eustomias* and the oceanic species concept. Unesco tech. pap. mar. sci. 49: 98-103.

Gieskes, W.W.C. & G.W. Kraay, 1989. Estimating the carbon-specific growth rate of the major algal species groups in eastern Indonesian waters by ^{14}C labelling of taxon-specific carotenoids. Deep-Sea Res. 36: 1127-1139.

Gieskes, W.W.C., G.W. Kraay, A. Nontji, D. Setiapermana & Sutomo, 1990. Monsoonal differences in primary production in the eastern Banda Sea. Neth. J. Sea Res., 25: 473-483.

Gjsæter, J., 1984. Mesopelagic fish, a large potential resource in the Arabian Sea. Deep-Sea Res. 31: 1019-1035.

Grice, G.D. & K. Hulsemann, 1967. Bathypelagic copepods of the western Indian Ocean. Proc. U.S. natl. Mus. 122 (3583): 67 p.

Halim, Y., 1969. Plankton of the Red Sea. Oceanogr. Mar. Biol. Ann. Rev. 7: 231-275.

Haq, B.U. & J.D. Milliman (Eds.), 1984. Marine geology and oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, New York, 382 pp.

Kabanova, J.G., 1968. Primary production in the northern part of the Indian Ocean. Oceanology 8: 214-255.

Kolla, V., P.K. Ray & J.A. Kostecki, 1981. Surficial sediments of the Arabian Sea. Mar. Geol. 41: 183-204.

Krey, J., 1973. Primary production in the Indian Ocean. I.In: B. Zeitzschel (Ed.). The biology of the Indian Ocean. Springer, Berlin, 115-126.
Krey, J. & B. Babenerd, 1976. Phytoplankton production. Atlas of the International Indian Ocean Expedition. University of Kiel, Institut für Meereskunde, 70 pp.
Longhurst, A.R. & D. Pauly, 1987. Ecology of tropical oceans. Academic Press, San Diego, 407 pp.
McClanahan, T.R., 1988. Seasonality in East Africas coastal waters. Mar. Ecol. Prog. Ser. 44: 191-199.
McGill, D.A., 1973. Light and nutrients in the Indian Ocean. In: B. Zeitzschel (Ed.). The biology of the Indian Ocean. Springer, Berlin: 53-102.
NIO, 1977. Proceedings of the symposium on warm water zooplankton. Special Publication National Institute of Oceanography, Goa, India, 722 pp.
Packard, T.T., D. Blasco & R.C. Dugdale, 1984. Coastal upwelling: a synopsis of its physical, chemical and biological characteristics. In: B.U. Haq & J.D. Milliman (Eds.). Marine geology and oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, New York: 339-350.
Poisson, A., S. Morcos, E. Souvermezoglou, A. Papaud & A. Ivanoff, 1984. Some aspects of biogeochemical cycles in the Red Sea with special reference to new observations made in summer 1982. Deep-Sea Res. 31: 707-718.
Rao, T.S.S., 1973. Zooplankton studies in the Indian Ocean. In: B. Zeitzschel (Ed.), The biology of the Indian Ocean. Springer, Berlin: 243-255.
Rao, T.S.S., 1979. Zoogeography of the Indian Ocean. In: S. van der Spoel & A.C. Pierrot-Bults (Eds.). Zoogeography and diversity in plankton. Bunge, Utrecht: 254-292.
Rochford, D.J., 1966. Distribution of Banda Intermediate water in the Indian Ocean. Aust. J. Mar. Freshw. Res. 17: 61-76
Ryther, J.H. & D.W. Menzel, 1965. On production, composition and distribution of organic matter in the western Arabian Sea. Deep-Sea Res. 12: 199-209.
Schalk, P.H., J.J. Zijlstra & J.IJ. Witte, 1990. Spatial and seasonal differences in acoustic recordings of the Banda Sea (Indonesia), obtained with a 30 kHz echosounder. - Neth. J. Sea Res. 25: 611-620.
Sharma, G.S., 1976. Transequatorial movement of water masses in the Indian Ocean. J. Mar. Res. 34: 143-154.
Sharma, G.S., 1978. Upwelling off the southwest coast of India. Indian J. Mar. Sci. 7: 209-218.
Smith, S.L., 1982. The northwestern Indian Ocean during the monsoons of 1979: distribution, abundance and feeding of zooplankton. Deep- Sea Res. 29: 1331-1353.
Smith, S.L., 1984. Biological indications of active upwelling in the northwestern Indian Ocean in 1964 and 1979, and a comparison with Peru and northwest Africa. Deep-Sea Res. 31: 951-967.
Smith, S.L., 1990. Science plan for U.S. JGOFS Process Study in the Northwestern Indian Ocean(unpublished draft U.S. Global Ocean Flux Study Steering Committee), 34p.
Smith, S.L. & L.A. Codispoti, 1980. Southwest monsoon of 1979: chemical and biological response of Somali coastal waters. Science 209: 597-600.
Slater, R.D. & P. Kroopnick, 1984. Controls on dissolved oxygen distribution and organic carbon deposition in the Arabian Sea. In: B.U. Haq & J.D. Milliman (Eds.) Marine geology and oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, New York, 305-313.
Spoel, S. van der, 1973. *Clio pyramidata* Linnaeus, 1767 forma *convexa* (Boas, 1886) (Mollusca, Pteropoda). Bull. Zool. Mus. Univ. Amsterdam 3: 15-20.
Spoel, S. van der, 1976. Pseudothecosomata, Gymnosomata and Heteropoda (Gastropoda). Bohn, Scheltema & Holkema, Utrecht. 484 pp.
Stubbing, H.G., 1939. The marine deposits of the Arabian Sea. An investigation into their distribution and biology. Scient. Rep. John Murray Exped. 3: 31-158.
Tijssen, S.B., M. Mulder & F.J. Wetsteyn, 1990. Production and consumption rates of oxygen, and vertical oxygen structure in the upper 300 m in the eastern Banda Sea during and after the upwelling season, August 1984 and February/March 1985. Neth. J. Sea Res., 25: 485-499.
Unesco, 1988. IOC Regional Committee for the co-operative investigation in the North and Central Western Indian Ocean. Second Session, Arusha, Tanzania, 7-11

Dec. 1987 (IOC Reports of Governing and Major subsidiary Bodies).
Warren, B., H. Stommel & J.C. Swallow, 1966. Water masses and patterns of flow in the Somali Basin during the southwest monsoon of 1964. Deep-Sea Res. 13: 825-860.
Weikert, H., 1980. The oxygen minimum layer in the Red Sea: ecological implications of the zooplankton occurrence in the area of the Atlantis II Deep. Meeresforschung 28: 1-9.
White, B.N., 1987. Oceanic anoxic events and allopatric speciation in the deep sea. Biol. Ocean. 5: 243-259.
Wyrtki, K., 1971. Oceanographic Atlas of the International Indian Ocean Expedition. National Science Foundation, Washington, D.C., 531 pp.

C

Tracing a Seasonal Upwelling

1. Introduction

Past and present organic productivity of the oceans show a wide range of variation. Today, high productivity areas are most prominent in upwelling zones, generally situated along western margins of continents (Peru, Gulf of California, SW- and NW- Africa). These zones constitute a significant component of the global carbon budget and bear directly on the ocean climate system.

In upwelling zones relatively cold, nutrient-rich waters are brought to the surface, resulting in very high rates of carbon fixation through photosynthesis, and in distinct chemical, physical and biological gradients in the water column. Since sediments, that accumulate directly underneath the upwelling zones preserve a record of bio-geochemical conditions in the water column and at the sediment/water interface during sedimentation, down-core studies of the sedimentary column allow for reconstruction of the temporal fluctuations of these conditions. A grid of samples across an upwelling area therefore will reveal both the temporal and the spatial fluctuations of these conditions and of their driving mechanisms.

A good understanding of the present day dynamics, processes and sediments of upwelling systems has been recognized recently as of key importance for the definition of paleo upwelling systems (SOHP, 1988). Especially the determination of, and the coupling between geochemical and biological tracers through time and their fluctuations as paleoclimatic indicators deserve attention.

In a review of JGOFS targets for the Indian Ocean (Smith, 1987), it was also pointed out that the nature and distinctive elements of diagenesis need a detailed study, especially the determination of fluxes of C, P, Si, O, and other characteristic elements in the water column and across the sediment/water interface. In addition, the mobilisation of elements in pore waters was pointed out to be of key importance for the ocean chemical budget .

2. Scientific Rationale

This study is undertaken to assess the structure and functioning, as well as the climatic and oceanographic consequences of the coastal upwelling zones off Somalia and Oman, and to arrive at a better understanding of the spatial and temporal variability of upwelling zones and their cyclicities.

2.1. Objectives and Applications

The first aim is to recognize environmental signals locked in the particles that form in the water column, settle, and ultimately become the sediment. The hydrographic, biological and chemical processes and products will be studied by measuring and sampling the water column. To determine variations of these processes and their effects on the composition of the sedimentary column over an annual cycle, moored sediment traps and in-situ tripod systems will be deployed and a time series measurement campaign in both the upwelling and the non upwelling period is performed.

The second aim is to determine which signals survive the descendance and burial processes. To that purpose we will sample and analyze the sediment/water interface, the surface sediments and the entrained interstitial fluids, as well as study the living benthic fauna and their respiration processes.

Then we will have the tools to achieve our final goal, to make reliable reconstructions of past physical and chemical conditions, that characterize upwelling signals in the NW Indian Ocean. That capability, to make high resolution, quantitative reconstructions, is needed to develop and test environmental and paleoclimatic models of global change. The studies will allow the determination of the relations between the development and presence of upwelling processes and the late Quaternary productivity, as well as of the implications of these processes for the fossil record.

To obtain a better knowledge of the spatial extent of the deposits, a reconnaissance seismic survey will precede the deployment of landers and the bottom sampling programme. Our seismic reconnaisance for core locations will also be directly applicable in accomplishing and complementing the main objective of ODP Leg 117: to trace the history of the monsoon system in the NW Indian Ocean. The results will be further relevant to resource exploration and management because sediments underlying upwelling systems are a potential source for hydrocarbon formation, because of the high contents of organic matter in combination with a rapid burial rate and anaerobic conditions. Also, diagenesis of organic matter and the development of anoxic conditions at or near the sediment/water interface results in remineralisation, the mobilisation of redox-sensitive elements and in the possible precipitation of a variety of authigenic products (as for example phosphates, opal and uranium).

2.2. The Upwelling Areas of Somalia and Oman

The NW Indian Ocean and the Arabian Sea have properties that are unique in the world, namely a seasonally reversing monsoonal gyre system which leads to a well developed, seasonal upwelling off Somalia and Oman (Figure C.1). During the International Indian Ocean Expedition (1965) a basic framework has been provided

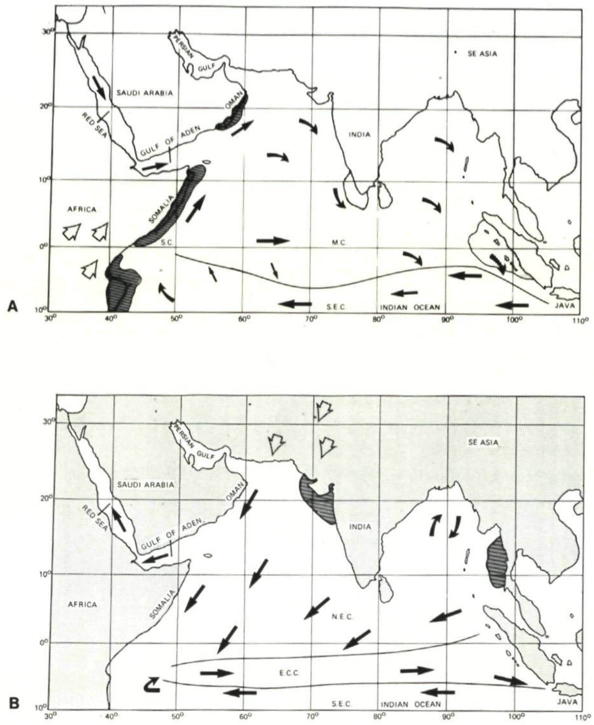


Figure C.1. Surface water circulation patterns in the northern Indian Ocean. (A) August, at the height of the southwest monsoon period (May to October). (B) February, at the height of the north-east monsoon period (November to April). Shaded pattern denotes regions of intense seasonal upwelling; hatched pattern areas of weak or sporadic upwelling. E.C.C. = Equatorial Counter Current; M.C. = Monsoon Current; S.C. = Somali Current; S.E.C. = South Equatorial Current.

concerning the larger scale hydrography and the chemical oceanography of the area. The GEOSECS expedition legs in the Indian Ocean (Weiss et al., 1983), refined the earlier expedition results, although the stations were situated quite far apart. The biology of the Indian Ocean has recently been reviewed by Zeitschel & Gerlach (1983). These studies show the importance of the strong, seasonally reversing monsoonal wind regime in the NW Indian Ocean and the Arabian Sea, which indirectly causes extreme, high ratios of primary production (over 500 mg C/m^2d) in the NW Indian Ocean, compared to the normal 100-150 mg over much of the world oceans (e.g. the Sagasso Sea). This high rate of primary production during the SW monsoon equals the primary productivity off Peru (Smith,1984) and is one of the main factors to cause the extreme oxygen minimum zone (OMZ) in waters between 200 and 1500 m depth at the continental margins of Oman, Pakistan and India (Wyrtki, 1973). In this oxygen minimum zone denitrification also is prominent (Deuser et al., 1978; Naqvi et al.,1982). According to Wyrtki (1973) the upper part of the OMZ is an oxygen sink because of the bacterial mineralisation. These processes and their variations in time thus strongly influence and determine the character and rates of diagenesis and the vertical distribution of elements in the sedimentary record.

The Somalia upwelling is associated with the occurrence of large eddies, under influence of the easterly directed Somali Current (Smith & Codispotie,1980; Bruce 1974). After the cessation of the SW monsoon, these eddies can still be identified during the early part of the next NE monsoon (Bruce et al., 1981). They may eventually reach as far east as the Oman Continental Margin and thus affect the sedimentation in the upwelling zone off Oman (D.Kroon, pers.comm.). The Somali upwelling region is known for its quick oceanic response to seasonal climatic changes. This in fact is also shown by Coastal Zone Colour Scanner remote sensing images of chlorophyll distribution over the period November 1978-June 1982.

The influence of the deep, near-bottom currents on sediment deposition processes in the Somali Basin and the continental margins of Somalia and Oman is unknown, while the inflow of deep and intermediate water from southern sources into the Somali Basin and Arabian Sea has been studied only to a moderate extent (Warren, 1984; Fieux & Swallow, 1988). The lack of detailed data of the deep water composition and circulation, especially with regards to its influence on dissolved oxygen content, possible organic carbon enrichment from the south , and possible sediment reworking, merits a thorough study of the water-column chemistry and of the near-bottom processes and their variations during an annual cycle.

Sediment studies of the Somali Basin are limited. DSDP sites in the SE Somali Basin and the Gulf of Aden were drilled before the introduction of hydraulic pistoncoring, and recovered insufficient sediment to reconstruct the late - Quaternary and Neogene sedimentation and the upwelling history or to determine the effects of deep water inflow on sedimentation.

Carbon isotope distribution in five pistoncores off Oman and the Gulf of Aden suggests that during the last Glacial, the NE monsoon was the more important feature (Fontugne & Duplessy, 1986) in areas where the productivity depends on the summer monsoon, it decreased at the beginning of the last Glacial. However, the time scales provided so far, need a better definition in the short (0-100) and medium (100-10.000 years) range. The study of selected expanded sections with high sediment accumulation rates could solve these problems, allowing for an estimate of sediment mixing using isotope tracers, and accumulation rate determination by means of radio isotopes on the 0,1-100 Ka time scale.

Prell & Curry (1981) studied Foraminifera in 17 core top samples from the Arabian Sea for their oxygen and carbon isotopes to relate these to the variations in hydrography and geochemistry during the upwelling periods. However, available hydrographic data were undiagnostic as they had been collected ten years earlier with outdated equipment. An extensive review of literature compiled for JGOFS (Smith, 1987) and for the ODP sites off Oman occupied in 1987 (Kroon, pers.comm.), fails to show any observation of time series measurements of biogeochemical components in the water column and at the sediment/water interface, for both the Somalia and the Oman upwelling zones.

In the Oman zone a sedimentary record extending down into the Miocene has been recovered recently during ODP leg 117 (Figure C.2). Basic objectives for leg 117 were to determine:

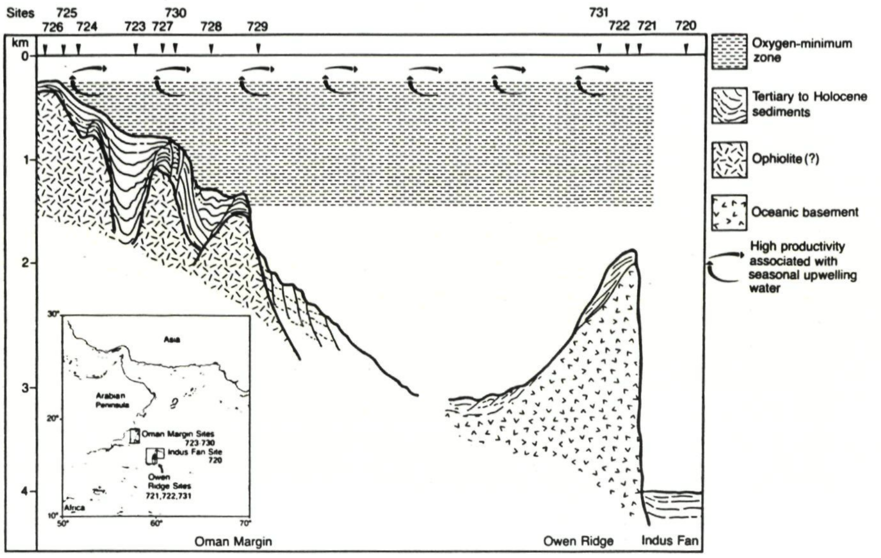


Fig. C.2. Leg 117 sites in the NW Indian Ocean (see inset), on an idealized transect across the continental margin off Oman. Sites 723-730 straddle the depths of a pronounced oxygen minimum zone that underlies the highly productive surface waters in areas of monsoonal upwelling. Sites 721, 722 and 731 are on Owen Ridge and reflect hemipelagic sediments influenced by high biogenic productivity.

- The history of Neogene monsoonal upwelling.
- The influence of monsoon intensity and of glacio-eustatic sea level fluctuations on productivity.
- The history of variations of the OMZ.
- Past variations in deep circulation from the sedimentary record of the Oman margin.

The cores obtained during leg 117 are being studied a.o. at the Geomarine Centre, Free University, Amsterdam (planktic and benthic foraminifera, stable isotopes of O, C, and Sr). Preliminary results indicate a cyclicity of 100.000 yrs in carbonate and organic carbon content, but it is not clear whether this signal represents cyclicity of productivity or not. To better interpret the sedimentary record there is an apparent need to know:

1) chemical gradients and fluxes in the water column (also of particles and biogenic matter);

2) the effects of early diagenesis and the remobilisation of elements;

3) which biogenic indicators in the sediment record the seasonal variations in productivity.

3. Project Specifics

3.1. Participants and Classification

Project management

Prof.dr. J.E. van Hinte
Geomarine Center, Free University,
P.O.Box 7161, 1007 MC Amsterdam

Dr. Tj.C.E. van Weering
Netherlands Institute for Sea Research, NIOZ,
P.O. Box 59, 1790 AB Den Burg, Texel

Participating institutes and responsible scientists:

Geomarine Center, Free University, Amsterdam
- K.Beets - geochemistry, rare earth elements, paleoproductivity
- G. Ganssen - $^{16}O/^{18}O$, $^{12}C/^{13}C$ isotopes, multinet, sediment traps
- J.E. van Hinte - forams, stratigraphy, geohistory
- S.R. Troelstra - benthic and planktonic forams;

Netherlands Institute for Sea Research, NIOZ, Den Burg, Texel
- R.P.M. Bak - protozoa
- A.J. van Bennekom - hydrography, CTD
- G.W. Berger - ^{210}Po, ^{210}Pb, ^{230}Th, scavenging
- G.J. Brummer - sediment traps
- S.J. van der Gaast - clayminerals, opal diagenesis, mineralogy
- W. Helder - organic carbon, nutrients, oxygen, fluxes
- J. van Iperen - diatoms, phytoliths
- T.C.E. van Weering - seismics/acoustics/ sedimentology, tripod measurements
- P.A.W. J. de Wilde - benthic respiration, bell jars, benthic landers meio/macro fauna

Delta Institute, Yerseke
- G.T.Klaver - rare earths in sediments, Br/organic carbon

University of Amsterdam
- H. Hooghiemstra - pollen

University of Bergen, Norway
- H. Schrader - diatoms

University of Kiel, Germany
- F. Sirocko - sedimentology
- K. Emeis - organic geochemistry

Classification

Disciplines and subdisciplines:
paleoceanography, marine geology, chemical oceanography, micropalaeontology, sedimentology

Areas of application:
global climatic change; mineral exploration, hydrocarbon exploration.

3.2. Experiments

A detailed, multidisciplinary study of the marine geology, sedimentology, chemistry and biology of (1), the upwelling area off Somalia (NW Indian Ocean) and (2) the upwelling area off Oman (NE Arabian Sea) will be carried out (Figure C.3), incorporating new, recently developed techniques to:

1) Establish a seismic and acoustic stratigraphy of the Somali Basin and adjacent waters.

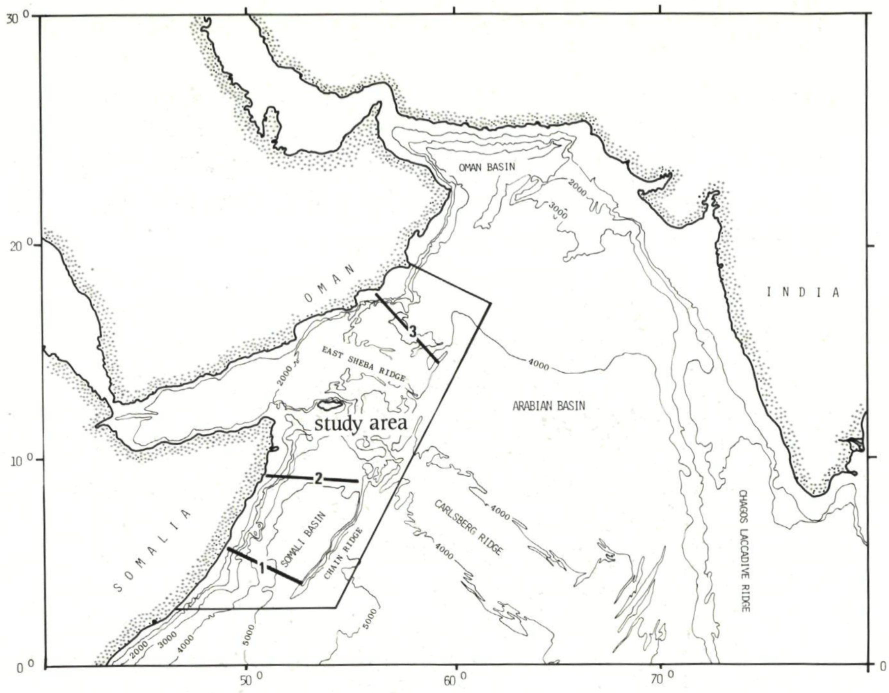


Figure C.3. Map showing NW Indian Ocean physiography and study area. Proposed sample transects indicated by heavy lines 1, 2 and 3. For location of ODP leg 117 sites see Fig. C.2.

2) Determine seasonal and spatial variations of physical, chemical and biological parameters characterizing the water column of a highly productive seasonal upwelling area.

3) Identify skeletal plankton and determine the distribution of species frequency and phenotypes in relation to (1).

4) Measure stable oxygen and carbon isotope ratios of the calcareous skeletons and of seawater.

5) Measure depth profiles of dissolved and particulate ^{234}Th, ^{210}Pb and ^{210}Po in the water column and in sediment trap material.

6) Measure the same as under (2) and (3) for the seafloor and subseafloor skeletons, including the benthos.

7) Measure fluxes of biogeochemical components through the water column and at the sediment water interface.

8) Assess the structure and functioning of the benthic communities and their respiration rates by in situ bell jar techniques.

9) Determine the influence of the variation in fluxes on the composition and character of the sediments and skeletal material (temporal and spatial).

10) Determine the fate of organic carbon and of the skeletal material during vertical transport and after sedimentation and burial.

11) Determine the effects and magnitudes of near bottom horizontal advective transport on sedimentation, to measure sediment accu-

mulation and -mixing rates and study their downcore variations in relation to fluxes and composition of particles measured in the water column.

12) Relate downcore variations in composition and lithology to the effects of the upwelling intensity and establish criteria and proxies for paleoproductivity.

3.3. Research plan

We plan to firstly conduct a seismic and acoustic reconnaissance survey of limited extent across the Somali Basin, and adjacent waters. This will be followed by the definite selection of sampling transects and locations for the deployment of sediment traps and emplacement of tripod systems and sediment traps. Subsequently extensive sampling will be carried out during (1) an upwelling situation (2) a non-upwelling and during both periods the same measurements will be carried out at the same stations, to specifically determine:

A) In the water column

The vertical distribution of temperature, salinity, oxygen, nutrients, Si/Al ratios, primary productivity, plankton content, organic carbon content (TOC), transmission, particulate matter and stable isotope ratios, Th isotopes.

These measurements will provide the basic data for a detailed study of the organic C degradation in an upwelling area during vertical transport in the water column, with emphasis on the processes and their rates in the predominant oxygen minimum zone between 300-1000 m, depending upon location (oxygen uptake and denitrification rate). The CTD-profiles of the water column and the chemical analyses of Go-Flow water samples for nutrients, oxygen, and nitrate will allow characterisation of the hydrographical regime and to model the rates of oxygen uptake and denitrification intensity in the water column.

The water column measurements will further determine vertical flux rates of organic C, plankton, carbonate and particulate matter, as well as of ^{230}Th. Spatially the comparison of the data will provide a three dimensional characterisation of intensity variations within and between the upwelling zones of Somalia and Oman. Comparison between the upwelling and the non upwelling situation will allow for a direct definition of the magnitude of seasonal variations between the parameters outlined above and the recording of these variations in skeletal associations, phenotypes and stable isotope ratios.

B) At the sediment-water interface and in surface sediments

- In-situ oxygen concentration in the surface sediments.
- Organic carbon content and carbon stable isotope ratios and signals.
- Pore water concentrations of nitrate, nitrite, ammonia, dissolved

Fe/Mn sulphate, silicate, Si/Al ratios.
- Carbonate contents.
- Br/C org ratios; REE.
- The structure and functioning of the benthic macro- and meiofauna, biomass, densities and distribution.
- Life benthic foraminiferal assemblage vs.dead assemblage.
- Ratio benthic foraminifers vs planktic foraminifers.
- Oxygen and carbon isotopes in planktic and benthic foraminifers.
- Diatom assemblages and opal formation in relation to extant clay minerals.
- Sediment composition and lithology, sediment mixing and accumulation by isotope determinations; REE distribution.

We expect that these measurements yield the transport rates and fluxes of the organic carbon, plankton, carbonate, nutrients and particulate matter through the sediment water interface, as well allow for flux measurements of Th isotopes. This will permit for an accurate determination of the effects and fluxes caused by early diagenesis in the sediments directly underneath the upwelling areas. Profiles of oxygen and sulfide in the boxcore sediments using micro-electrodes will allow comparison with the in-situ determined oxygen profiles. Related research has been carried out in other areas, notably during JGOFS 1989 cruises in the North Atlantic Ocean (for relevant literature see: Helder & Bakker, 1985; Helder & Andersen, 1987; Helder, 1989).

In addition, the relationships between benthic foraminiferal and physical/chemical parameters, in particular oxygen and organic carbon, will be established for upwelling zones. The fate and the rate of organic carbon degradation and settling will be established, including definition of burial rates under different oxygen conditions.

Comparison between the results from the two upwelling zones will yield definition of the magnitude of the seasonal differences between the two systems. Comparison between results of measurements during the non-upwelling and the upwelling situation will yield a more accurate definition and characterisation of magnitudes and variations of upwelling signals in the bottom sediments.

C) Downcore sediment studies

The downcore measurement of a number of the variables described under A and B above, in combination with the analysis of the micropaleontological records, will result in the establishment of short (10-100 yrs), medium (0.1-10 ka) and long (10-100 ka) term fluctuations of these parameters and thus of estimation of the cyclicity of the upwelling patterns on different time scales. The latter will be checked by measuring ^{230}Th isotopes in the piston core sediments. It is expected that this will not only yield absolute age determinations, but also an assessment of paleoproductivity, because of the dependency of ^{230}Th fluxes into the sediments on productivity. The latter can be checked against diatom accumulation rates and downcore measurement of the ratio Br/org.C. This ratio ranges from 50-60 in upwelling areas around the world and contrasts strongly with the ratio of about 20 measured in non-upwelling areas such as the Mediterranean (Figure C.4).

The variations in the Br/organic C ratio in ODP site 728 cores ranges from 60 to 10. These variations were explained by assuming the alternation of periods of non upwelling and upwelling. However, such variations are also explained by removal of organic matter during early diagenesis. The programme and measurements described above allow for a definite correlation with either paleoproductivity or, alternatively, selective storage of Br in the sediment during remineralisation of the organic material.

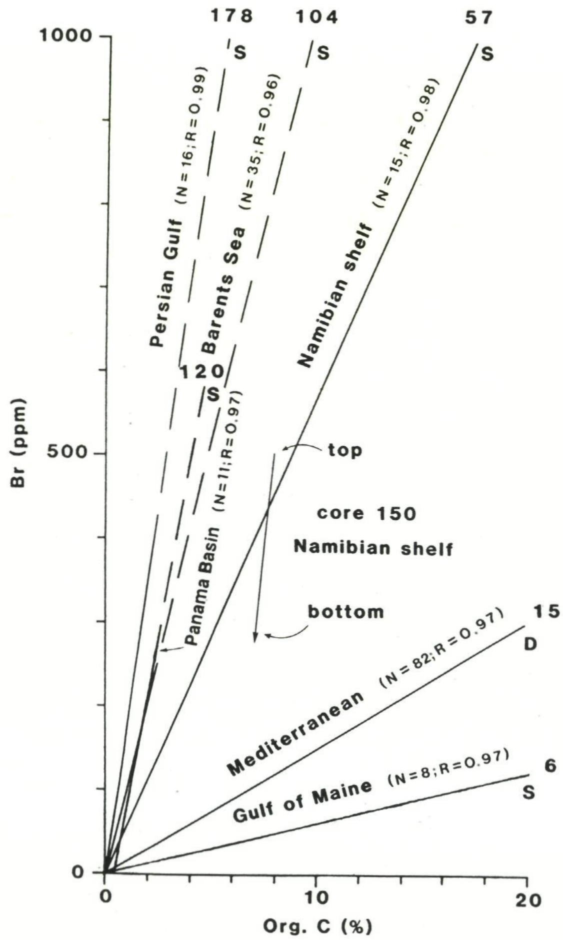


Figure C.4. Ratios of Br/C-organic for various depositional environments.

The downcore distribution of clayminerals and of the content and character of the opal fraction will yield more details on the prevailing wind regimes and their temporal fluctuations. These data will complement the data collected by Sirocko (1989) for the NW Arabian Sea.

3.4. Methods, Equipment and Facilities

For the studies indicated we have access to and are building a number of new instruments, in addition to the equipment provided by the Netherlands Marine Research Foundation (SOZ). The emplacement of a series of moored sediment traps with multiple collection devices at various depths, will allow for time series measurements of the flux variations described above from the non-upwelling period to the upwelling period. A tripod mounted in-situ oxygen profiler will be used to estimate the oxygen profiles in the surface sediments (Reimers et al., 1986).This instrument is equipped with oxygen micro-electrodes and with a sediment resistivity probe to be able to modify free solution diffusion coefficients to whole sediment diffusion coefficients. The tripod has been successfully tested during JGOFS 1989 in the North Atlantic Ocean and will be available for this study.

Deployment of a lander-based benthic chamber and sampler is planned for the estimation of fluxes of solutes and oxygen across the sediment/water boundary, and to establish and assess the respiration rates of the benthic communities at the sea floor. The instrument has been successfully tested under deep water conditions in the NE Atlantic Ocean during JGOFS 1990, allowing time series measurements over periods up to 48 hrs . Similarly, deployment of a moored tripod for long term in-situ time-series measurement of temperature, salinity, and transmission against continuous current velocity and direction measurements (in combination with stereo bottom photography) will allow definition of the near bottom horizontal water transport and its effects on the fluxes described above during a seasonal cycle.

During the last years a box core to sample undisturbed sediments and pore waters, and perfectly preserving the directly overlying bottomwater has been constructed.This boxcorer will be equipped with underwater TV to allow for sampling accuracy. Profiles of oxygen and sulfide, made using micro-electrodes in the boxcore sediments, will allow comparison with the in-situ determined oxygen profiles.

Conventional 3.5 khz and single channel high resolution seismic reflection techniques will be applied prior to and during sampling, to establish a regional seismic and acoustic framework of the Somali Basin and adjacent waters. The underway acoustics will also be used for the selection of sampling transects and for the accurate location of station sites, and assessment of sediment trap and tripod deployment locations. CTD data and water samples will be collected at the stations by means of Rosetteframe equipped with multiple sensors and with Go-Flow water samplers. Multiple plankton nets, box corers and piston corers will be applied for the additional collection of samples. For the study of fluxes of Th isotopes in the water column and for in-situ measurement of depth profiles of particulate ^{234}Th, an underwater pumping and filtration system is needed.

3.5. Training and education

Due to the wide range of activities to be carried out at sea during this project, ther are but few possibilities for shipboard participation of scientists or technicians. Post-cruise training, in the form of joint analysis of data and/or participation in M.Sc. or Ph.D. courses in Marine Geology can be offered by the Free University of Amsterdam and the NIOZ. However, this depends on the (limited) availibility of the fellowships to be provided under the Programme and to additional funding possibilities.

4. References

Bruce, J.C., 1974. Some details of upwelling of the Somali and Arabian Coasts. J.Mar Res. 32: 419-423.

Deuser et al., 1978. Evidence for and rate of denitrification in the Arabian Sea. Deep Sea Res. 25: 431-455.

Fieux, M. and Swallow,J.C., 1988. Flow of deep water into the Somali Basin.Deep Sea Res. 35: 303-309.

Fontugne, M.R. and Duplessy, J.C., 1986.Variations of the Monsoon regime during the Upper Quaternary; Evidence from Carbon isotopic record of organic matter in North Indian Ocean sediment cores. Paleo .Paleo .Paleo 56:69-88.

Helder, W., 1989. Early diagenesis and sediment water exchange in the Savu Basin (Eastern Indonesia). Neth.J.Sea Res., 24(4); 555-572

Helder, W., & Andersen, F.O., 1987. An experimental approach to quantify biologically mediated dissolved silicate transport at the sediment-water interface. Mar.Ecol.Progress.Ser. 39: 305-311.

Helder, W. , & Bakker, J.F., 1985. Shipboard comparison of micro- and mini electrodes for measuring oxygen distribution in marine sediments. Limnol. and Oceanogr. 30: 1106-1109.

International Indian Ocean Expedition, Collected Reprints, 1965. Unesco, Paris.

Naqvi, et al ., 1982. Denitrification in the Arabian Sea. Deep Sea Res. 29: 459-469.

Prell, W.L., & Curry W.B., 1981. Faunal and isotopic indices of monsoonal upwelling: Western Arabian Sea. Oceanologica Acta 4: 91-98.

Reimers, C.E., Fischer, K.M., Merewether, R., Smith, K.L.,& Jahnke, R.A., 1986.Oxygen microprofiles measured in situ in deep ocean sediments. Nature 320:741-744.

Sirocko, F., 1989. Accumulation of eolian sediments in the northern Indian Ocean; record of the climatic history of Arabia and India. Reports Geol-Paleont.Inst. der Univ.Kiel, Nr 27, 185 pp.

Smith, S.L., 1984. Biological indications of active upwelling in the NW Indian Ocean in 1964 and 1979. Deep Sea Res. 31A: 951- 967.

Smith, S.L., 1987. The Indian Ocean as a GOFS site.Report for U.S.GOFS Steering Committee. 11pp.

Smith, S.L., & Codispotie, L.A., 1980. South west Monsoon of 1979: Chemical and biological Response of Somali Coastal Waters. Science 209: 597-600.

Sohp, 1988. Joint sediments and ocean history panel; section on upwelling and productivity. 5pp

Warren, B., 1984. Deep circulation of the Indian Ocean. Proc. Workshop on Oceanog raphy of the Indian Ocean.Rosenstiel School for Marine Sciences, University of Miami: 13 pp.

Weiss et al., 1983. Geosecs Indian Ocean Expedition.Vol. 5, Hydrographic Data,Nat.Sc.Foundation, Washington,USA.

Wyrtki, K., 1973. Physical Oceanography of the Indian Ocean.In: B.Zeitschel (Ed.) Ecological Studies, Springer, 18-36.

Zeitschel, B., & Gerlach, D., 1983.The biology of the Indian Ocean. Springer,New York.

D Geological Study of the Arabian Sea

During ten successive weeks a marine geological survey will be carried out in the Arabian Sea. The survey time is divided into three consecutive legs, separated by portcalls in Karachi, Pakistan. The Project aims to address two specific scientific objectives, one to establish the Late Quaternary Productivity and the Dynamics of the Oxygen Minimum Zone (D1), the other to define the Depositional Architecture and Sediment Facies of the Middle to Lower Indus Fan (D2). Project D1 will be studied in each of three separate areas during legs 1, 2 and 3; leg 1 exclusively in international waters, leg 2 covering a substantial part of Pakistan's EEZ and leg 3 that of Oman. Project D2 will be active only in area 1 during leg 1 (Figure D.1)

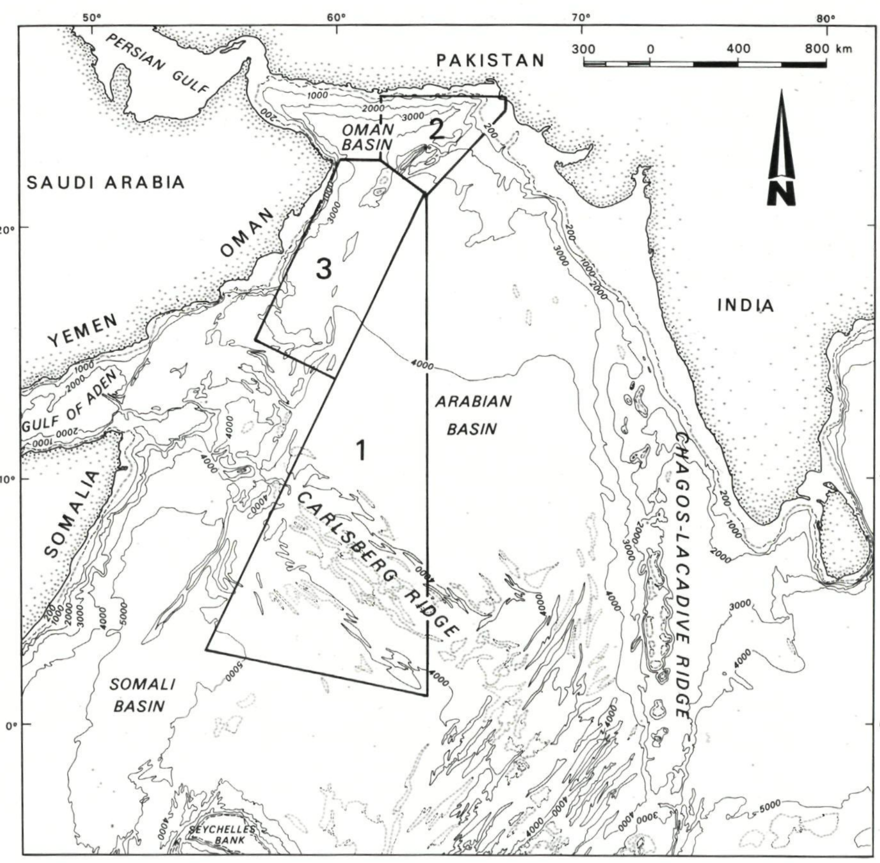
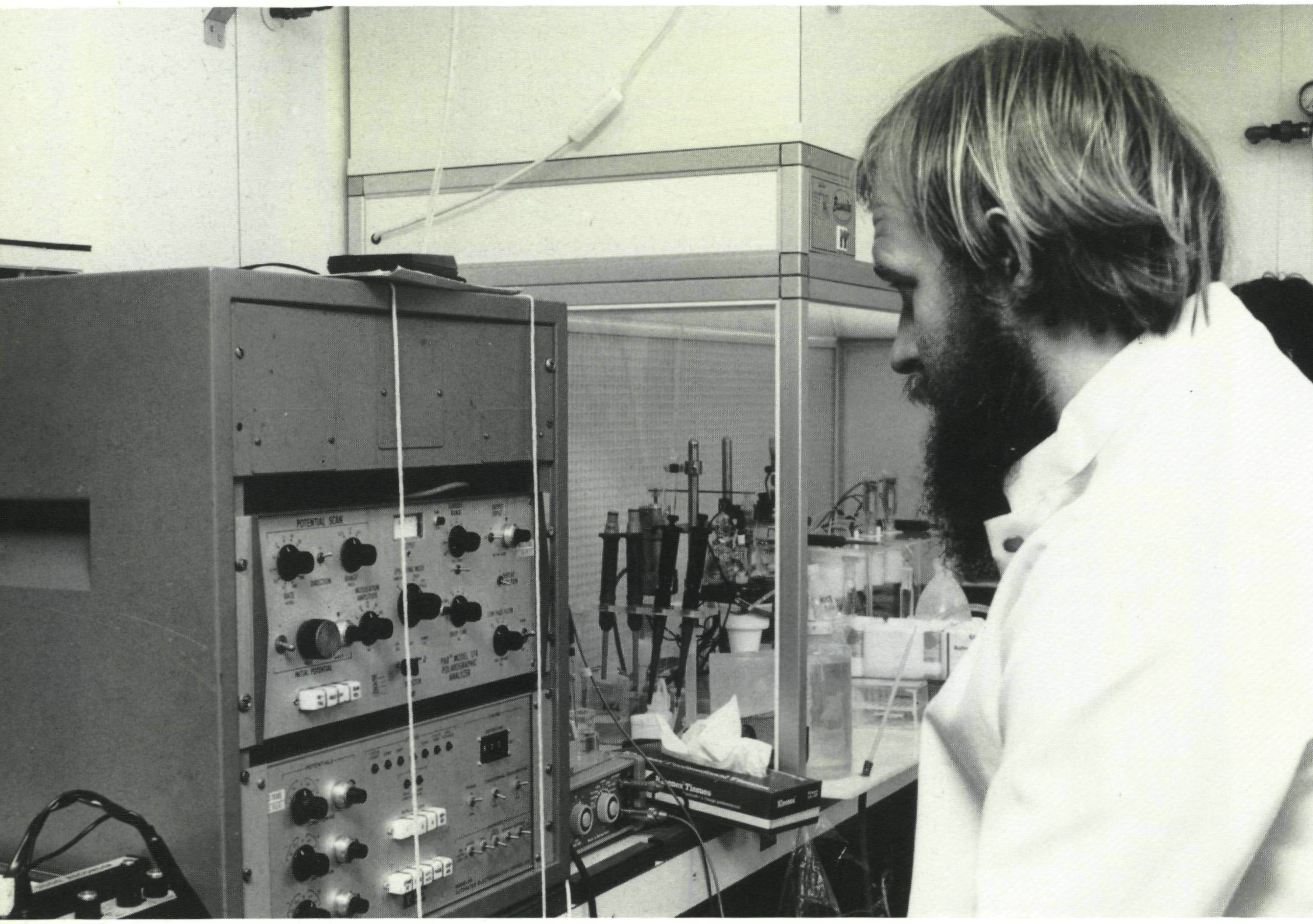


Figure D.1: Map of the N.Indian Ocean, with indication of legs and areas of interest (areas 1, 2, and 3).



D1

Late Quaternary Productivity and the Dynamics of the Oxygen Minimum Zone

1. Introduction

Most parts of the ocean show an O(xygen) M(inimum) Z(one) (Figure D1.1) at intermediate depths (150 - 1000 m). This oxygen depleted zone is the result of a balance between oxygen consumption by oxidation of organic detritus and renewal of oxygen by advection and turbulent mixing. Influx of oxygen by mixing with the atmosphere as well as production by photosynthesis ensures a high oxygen content in the surface layer. Maximum consumption rates and limited downward mixing depletes the water of oxygen below the surface mixed layer. At greater depths, oxygen levels will increase again because of upward transport of oxygen from deeper water and lower oxygen consumption rates.

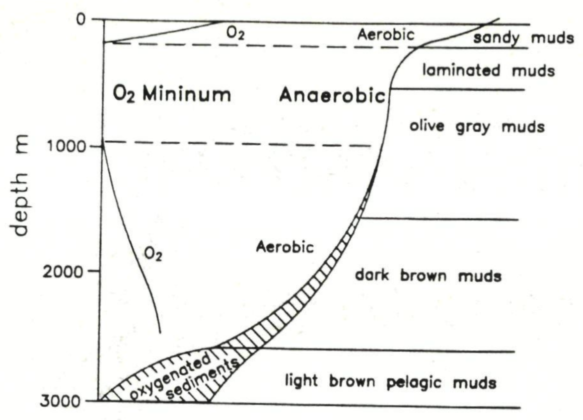


Figure D1.1: Schematic representation of the redox regime near the continental slope in the N.Indian Ocean and of concomitant typical slope sediments.

In the Arabian Sea (Figure D.1) the OMZ with minimum concentrations of less than 0.2 ml/l is found between 200 and 1000 m (Wyrtki, 1973). High consumption rates at these intermediate depths are maintained by high average production rates of organic Carbon in the surface layer due to strong coastal upwelling off Somalia and along the southern coast of Arabia during the SW Monsoon, and weak coastal upwelling along the NW coast of India and Pakistan during the NE Monsoon (e.g. Wyrtki, 1971; Schott, 1983; Swallow, 1984). Apart from supply through advection oxygen concentrations at intermediate depths depend also on lateral inflow. For the Arabian Sea, however, the lateral inflow of oxygen from northern and southern sources is rather insignificant for two reasons:

1)Two northern sources of intermediate water in the Arabian Sea, Red Sea water and Persian Gulf water, have moderate oxygen concentrations of approximately 3 ml/l (e.g. Tschernia, 1980; Swallow, 1984). Because both sources are small in volume their contribution to the oxygen balance is minimal (Siedler, 1968; Koske, 1972).

2)Dissipation and subsequent dilution of Red Sea and Persian Gulf water into the Arabian Sea requires a relatively large flux of low salinity water in order to maintain dilution rates in a steady state (Swallow, 1984). This water of southern origin has a much greater volume transport than that from the northern sources and could, therefore, be a more important source of oxygen supply in the Arabian Sea than waters from northern sources. The southern water seems to have an intermediate and a deep component (Swallow, 1984). The intermediate component has various sources but probably not much of this intermediate water goes directly into the Arabian Sea. According to Swallow (1984), the equatorial region acts as a holding tank in which the dissolved oxygen of the relatively new intermediate water (i.e. Central Water and Antarctic Intermediate Water) decays and is reduced by mixing with older water (i.e. from the Banda Sea) before it reaches the Arabian Sea. The exchange of intermediate water is most likely controlled by Arabian Sea upwelling.The deep water component (i.e. below 2000 m) in the Arabian Sea consists of mixtures of Atlantic Deep Water and Antarctic Bottom Water. This deep water has moderate oxygen concentrations of 2.5 to 4 ml/l (Tschernia, 1980) and wells up to compensate for its sinking at high latitudes (Warren, 1981).

The Arabian Sea OMZ, thus, appears to be the result of excessive consumption, combined with a large volume transport at intermediate depths of oxygen-depleted water of southern origin.

2. Scientific Rationale

2.1. Late Quaternary Productivity in the NE Arabian Sea

Present-day, i.e. post-glacial, anaerobic mid-water conditions in the Arabian Sea are primarily controlled by excessive oxygen consumption caused by a high production of organic C in the surface water layer. The production of organic C, in turn, is primarily controlled by the strength of the monsoonal system. Intense coastal upwelling takes place in the NW Arabian Sea during the SW Monsoon, whereas (weaker) coastal upwelling along the west coast off India and Pakistan is active during the NE Monsoon.

The situation during glacial times is uncertain. Did Pleistocene glacial conditions influence the pattern of the monsoonal regime and, if so, what effect did this have on regional productivity? Late Quaternary climatic reconstructions by Van Campo et al. (1982), Prell & Van Campo (1986) and Fontugny & Duplessy (1986) suggest that the NE Monsoon was the dominating feature in glacial times, whereas the SW Monsoon, as it does today, prevailed during the interglacials.

To substantiate or modify these reconstructions it is necessary to establish a detailed record of surface water productivity during the last glacial (I). Such a record can also be employed to determine whether or not there is a causal relationship between primary productivity and thickness of the OMZ in the Arabian Sea (II). Such a relationship has been proposed by Southam et al.(1982) but has not yet been substantiated by sediment data.

Paleoproductivity (I)

Sediments deposited under varying seasonal conditions in anaerobic environments are usually varved. Such varved sediments have been found at the intersection between the OMZ and the continental slope off west India (Von Stackelberg, 1972). Varved sediments are highly suitable for recording temporal and long-term variations in surface water productivity. Past productivity conditions are probably best described by a) the relative distribution of the planktonic foraminifer Globigerina bulloides, b) the ratio of heterotrophic/ autrophic dinoflagellate cysts, c) the flux rates of selected groups of microfossils, d) the abundance and composition of organic C and e) the carbon/carbonate ratio.

Marine organic C consists of a melange of microscopic relicts of land plants (i.e pollen, spores, cuticulae, wood, fungi) and of aquatic organisms (algae, bacteria). A palynofacies study of the insoluble organic fraction will furnish evidence of the terrigenous or marine origin and transport mechanism (river-borne or wind-blown) of organic matter. In combination with (non-organic walled) micropalaeontological, sedimentological and geochemical information derived from the same material, palynofacies studies are a very powerful technique for reconstructing past productivity conditions and climate during the Late Quaternary (Caratini et al., 1981; Caratini & Tissot, 1985).

Productivity and thickness of the OMZ (II)

Past variations in thickness of the OMZ are probably best traced at the present-day upper and lower limits of the OMZ. At these boundaries the abundance and composition of benthic foraminiferal in-fauna, lithology, and organic C content are sensitive recorders of past variations of dissolved oxygen in the bottom water and thus of past variations in the upper and lower depth limit of the OMZ. Since both consumption and renewal processes at mid-depths are linked to wind-stress (Swallow, 1984) and since consumption exerts maximum control on the mid-water oxygen balance, past changes in the mid-depth circulation will probably sharpen the effects invoked by changes in surface water productivity only slightly.

Higher production rates of Antarctic Bottom Water during glacials (e.g. Ledbetter, 1977) must have increased the rate of upwelling of deep water in the Arabian Sea. At the same time, however, North Atlantic Deep Water production was probably severely reduced (e.g. Mix & Fairbanks, 1985; Boyle & Keigwin, 1987). Therefore, upwelling rates of deep water in the Arabian Sea may not have changed significantly over the last glacial cycle. It is thus worthwhile to examine whether benthic foraminifers in the deep Arabian Sea show evidence of glacial/interglacial changes.

2.2. The Relationship between the Distribution of Oxygen and the Microhabitat Differentiation of Benthic Forams

Few in-situ studies have focused on the relationship between composition and standing stock of benthic foraminifers and oxygen distribution in bottom water and the upper sediment layer. Models which describe these relationships are based on examples from the fossil record and need to be tested and refined by in-situ studies (e.g. Verhallen, 1987; Jorissen, 1988). Fossil benthic foraminiferal species are ranked in a similar manner in terms of their gross tolerance to oxygen deficiency. Only a few in-situ studies relate the distribution of benthic foraminiferal species to the distribution of oxygen in bottom water and sediment (Mullins et al., 1985; Corliss, 1985). To define better how specific and phenotypic variations in benthic foraminifers and their depth distribution in the sediment are interrelated with the distribution of oxygen in bottom water and sediment it is necessary to recover and study a detailed set of box cores across the OMZ. The resulting information will be directly applicable to studies pertaining to the assessment of past variations in thickness of the OMZ. In addition, this type of information should point out the degree of symmetry in benthic foraminiferal patterns across the OMZ. Symmetrical patterns are recorded across the OMZ off central California (Mullins et al., 1985), whereas Late Quaternary sapropels from the deep Mediterranean show a strong asymmetric in-faunal pattern (Jorissen, in prep.). The symmetry of in-faunal patterns therefore may be an important criterion to distinguish fossil mid-water anoxia from deep-water ones.

2.3. The Distribution Patterns of Dinoflagellate Cysts

Studies of modern distribution patterns of dinoflagellate cysts have thus far been carried out mainly in the Atlantic Ocean. These studies cover fresh-water to mid-ocean environments and their results have greatly stimulated employment of dinocysts in paleoenvironmental studies (e.g. Wall et al., 1977; Harland, 1977; Dale, 1983) . To fully employ dinocysts for that purpose, however, more data are required on their nearshore to offshore distribution, preferably in areas other than the Atlantic Ocean.

Data from the area of the Arabian Sea are limited to the Persian Gulf and Oman region (Bradford & Wall, 1984). The low-oxygen environments on the relatively wide and fertile W. Indian shelf area and adjacent OMZ enhance the preservation of organic-walled dinocysts. The area, therefore, provides a unique setting for mapping the nearshore to offshore dinocyst distribution. Resulting data will be used to portray distribution patterns of heterotrophic and autrophic dinocysts and their relation with surface water productivity.

Studies focusing on sea level fluctuations rely heavily on modern examples which relate dinocyst distribution to waterdepth and to distance to shore (e.g. Brinkhuis & Zachariasse, 1988). To enable full employment of dinocysts in the study of sea level change, it is necessary to increase our understanding of the relation between their abundance and composition and their depth range and distance to shore. In this respect a sampling program of the shelf and slope area off west India will be a useful exercise. Dinocyst abundance and composition in surface sediments can furthermore be compared with data on the dinoflagellate distribution in surface waters of the Arabian Sea to establish relationships between cysts and theca (motile stages) (Cleve, 1903; Schröder, 1906).

Note

The data set to be collected from the NE Arabian Sea to meet the objectives will complement the information gained from ODP sites 723-730, which were drilled and cored recently during Leg 117 across the Oman margin (Prell et al., 1988). The Leg 117 information particularly should establish the Neogene evolution of the SW monsoon and its influence on local upwelling and productivity. In order to establish the complete picture of glacial influence on the oceanography and productivity (and thus on the shape of the OMZ) in the entire Arabian Sea, however, it is essential that micro-palaeontological, sedimentological and geochemical information is obtained also from the northeastern margin.

2.4. The Effect of Low Oxygen Bottom Water

Organic matter is the dominant fuel that allows the diagenetic motor to run at various speeds. Most early diagenetic processes find their origin in the microbial decomposition of organic matter. The fate of organic carbon in the water column and the sediment, in relation to paleoproductivity or bottom water oxygen content has been discussed extensively in the literature (e.g. Emerson, 1985; Reimers, 1988 and refs. therein). Only the last two decades, however, have seen some progress in quantifying these processes and in the determination of the actual mechanisms of decomposition of organic matter. Several successive stages are recognized in the decomposition process. Each one of these depends on the stability of components in the fractions, being 1. very labile, 2. labile and 3. refractory (e.g. Berner, 1980; Emerson et al., 1987; Reimers, 1988; c.f. Figure D1.2).

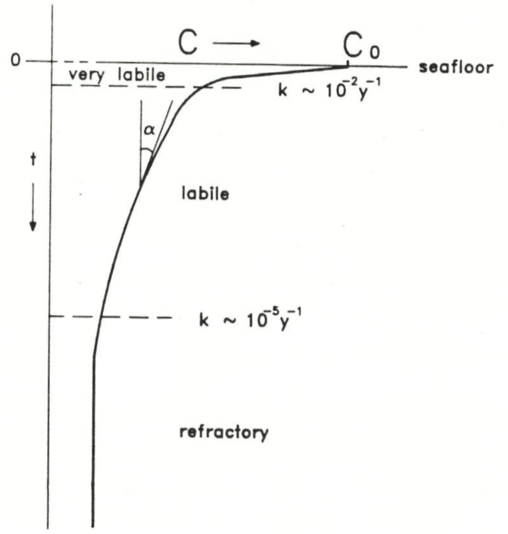


Figure D1.2: Schematic profile of organic matter content vs time (depth) in marine sediments. Typical rate constants (k = tan α) for degradation of very labile, labile, and refractory components are indicated and decrease with time.

Fraction 1 (very labile) is decomposed rapidly ($k > 10^{-2}$/yr) in the water column and at the sediment-water interface. Reportedly decomposition through oxygen or sulphate, under oxidized respectively under reduced conditions occurs rapidly as well at similar rates within a factor of 2 to 3. This means that for most deep sea sediments the very labile fraction will be decomposed within a few months after deposition. Fraction 2 (labile) is decomposed at the sediment-water interface or in the sediment at moderate rates ($k = 10^{-2}/yr$ to $10^{-5}/yr$); the decomposition rate of part of this fraction seems to be controlled by the presence of oxygen. Depending on sedimentation rate, bottom water oxygen content, and the organic carbon content of the sediment in question, part of fraction 2 may be buried. Fraction 3 (refractory) is the fraction that is mostly preserved under normal, low temperature, early diagenetic conditions. Below the zone of oxygen penetration decomposition of this fraction continues very slowly, i.e. several orders of magnitude slower than under oxic conditions ($k < 10^{-5}/yr$). Fractions 2 and 3 constitute the organic carbon 'paleosignal' in the sediment. The potential difference in organic matter decomposition rates under oxic and anoxic conditions has been subject of discussion for some years (e.g Emerson, 1985; Reimers, 1988; Thierstein, 1988). These differences are important, as cyclic variability in organic carbon in marine sediment may be interpreted as a record of variable paleoproductivity and bottom water oxygen content.

As much as 10% organic carbon content was found in continental slope sediments off the coast of W. India (Kolla et al., 1981). This percentage can be attributed to a combination of high productivity and oxygen depletion in the intermediate bottom water. A high productivity and low oxygen concentration also exists at the Oman Margin. There, however, the preservation of organic matter in the sediment is much lower than at the Indian Margin. The reason for these differences is poorly understood and justifies a detailed study.

Once organic matter enters the sedimentary column further degradation takes place by oxic, suboxic and anoxic bacterially induced processes. These processes bring about a suite of secondary reactions that exert a major influence on the sediment geochemistry: dissolution of iron and manganese oxides, reduction of sulfate and formation of metal sulfides (e.g. pyrite), dissolution or precipitation of carbonates, and, eventually, formation of phosphorite (e.g. on the continental margins off Peru and West India). In addition diagenetically induced deviations in the isotopic composition of hydrogenous precipitates have been found (Siddiquie et al., 1984). The intensity of these processes depends on a combination of lability and quantity of the organic matter that enters the sediment column. Information on the intensity of these processes (e.g. degradation rates, amount of reaction products) can be obtained from the geochemistry of pore waters and sediments.

The study of marine pore waters is a powerful technique in the diagnosis of diagenetic processes and their bearing on sedimentary regimes (e.g. De Lange, 1986). Earlier studies on pore water chemistry in the area (Marchig, 1972) lacked precision and sophistication and the published results are not suitable for diagenetic interpretation. Currently available analytical techniques will allow routine gathering of large amounts of data useful for performing very high resolution chemostratigraphic studies. These methods will enable a study of sub-recent migration in quality and quantity of inorganic and organic particulates toward the sediment surface.

This type of study will fit in well with envisioned multidisciplinary studies of Late Quaternary paleoenvironmental conditions in this part of the world ocean. The geochemical studies require box cores and piston cores in a number of transects south off Pakistan. This area has NE-monsoon-driven periods of higher productivity and the effects of that are expected to be preserved in the sedimentary record. Emphasis will be placed on cores below and above the edges of the present-day OMZ. Box cores will be used to study the (sub)recent situation whereas piston cores will be used to analyze past variations in the upper and lower depth limit of the OMZ.

In order to establish these patterns in the entire Arabian Sea, a similar study is necessary in a transect off Oman, where the sedimentary record of SW-monsoon-driven periods of higher productivity can be studied. Detailed studies on pore water chemistry and chemostratigraphy in the upper sediments can be combined with other studies in the area (e.g. those linked to ODP leg 117; Prell et al., 1988).

A promising test site for studies of early diagenesis far from land is the Owen Ridge where Milankovitch-type sequences of organic-rich and organic-poor beds were found by the shipboard party of ODP Leg 117. A detailed pore water study of the upper part of the sediment column will greatly assist in the interpretation of the paleoenvironmental history in this part of the Indian Ocean.

2.5. The Role of Present-Day Anoxia

The organic content and mineral composition of sediments is partly controlled by the redox conditions in the overlying water column. Redox-sensitive elements and components show remarkably different behaviour under oxic and anoxic conditions. Some components are far less soluble under oxic than under anoxic conditions (e.g. Fe, Mn, Ce), whereas others show the reverse (e.g. V, Cr, U, Sb, As, Mo). At the pH of sea water the redox boundaries for the transition of the oxidized into the reduced state (or vice versa) of these elements lie in the so-called suboxic region, between oxic (fully oxygenated) and anoxic (sulphate reduction) conditions (Figure D1.3, modified after Turner et al., 1981). This region coincides exactly with the variations in the OMZ in the Arabian Sea: present-day suboxia (denitrification!; Sen Gupta & Naqvi, 1984; Naqvi et al., 1982) and in the past presumably periods of anoxia due to a somewhat smaller advection of oxygenated bottom water. The analysis of water, of suspended matter and of surface sediments above, within and below the OMZ will provide the data that are necessary to assess the role of the present-day conditions in the distribution of redox-sensitive elements between sea water and particulates. Of special interest is the comparison of the thermodynamic predictions based on figure D.5 and the actual behaviour of these elements (to be determined on the basis of high quality data).

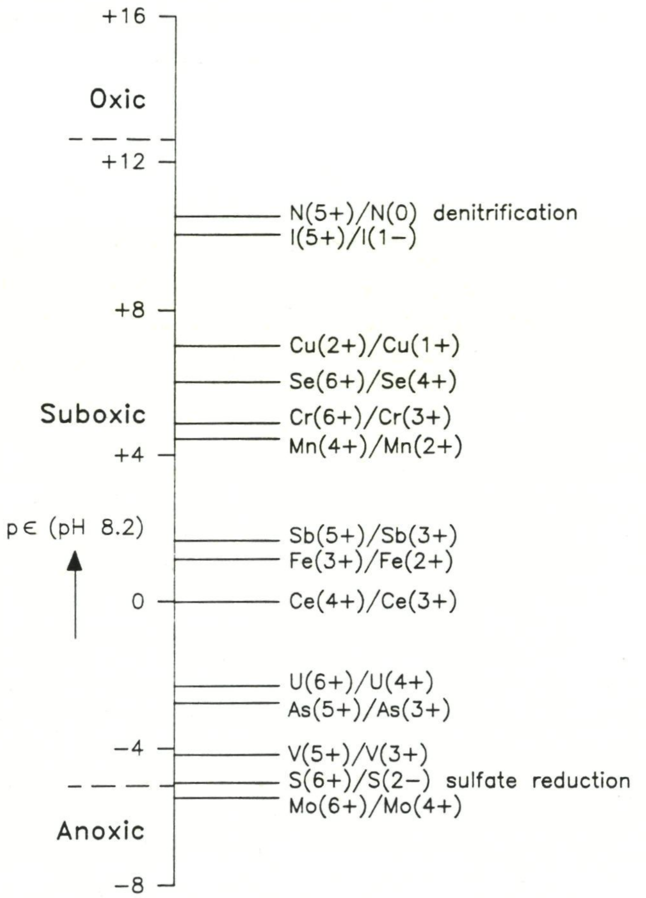


Figure D1.3. Redox boundaries in pE units at pH 8.2 in seawater for the redox couples as indicated.

So far little research has been done on the marine geochemistries of some of these elements, particularly As, V, Mo, U (cf. Collier, 1985; Middelburg et al., 1988). The understanding of the behaviour of redox- sensitive elements under the actual conditions within and beyond the OMZ is a prerequisite for the diagnosis of their concentrations and variations in the sedimentary record. The analysis of such elements in sub-recent sediments can then be used as one of the means to reconstruct the redox conditions during the time of their deposition. Post-depositional diagenesis and concomitant mobilization of these elements may make this reconstruction more complicated (e.g. Wilson et al., 1986; De Lange et al., 1986). In combination with the micropalaeontological record, however, this study will be a powerful method for the understanding of paleo redox conditions in the Arabian Sea during the Quaternary. A basin-wide record of good data is required along a transit that includes the OMZ's off the Oman and Indian continental margins, as well as in the central area in between. The study demands the clean collection of water (GoFlo bottles) of suspended matter (by centrifugation of about 1 m^3 water) and the collection of sediments (by box and piston cores). Clean onboard sample treatment in adequately clean laboratories is a prerequisite for obtaining high quality analytical data.

3. Project Specifics

3.1. Participants and Classification

Project management:

Dr. W.J.M. van der Linden (leg 1 and leg 2)
Prof.Dr. C.H. van der Weijden (leg 3)
Working Group Marine Earth Sciences
Faculty Geology & Geophysics,
University of Utrecht
P.O. Box 80.021, 3508 TA Utrecht
The Netherlands
tel. (31) (0)30 - 535050;
fax. (31) (0)30 - 535030

Participating institutes and responsible scientists:

Working Group Marine Earth Sciences, University of Utrecht.
Prof.Dr. C.H. van der Weijden - geochemistry
Dr. G.J. de Lange - geochemistry/pore water analysis
Dr. W.J. Zachariasse - micropalaeontology, paleoceanography
Dr. W.J.M. van der Linden - acoustics, site surveys
National Institute of Oceanography, Karachi, Pakistan
Dr. Athar Ali Khan
Ministry of Agriculture and Fisheries, Sultanate of Oman
Dr. Thabit Zahran al Abdisalaam
Laboratory of Palaeobotany and Palynology, University of Utrecht.
Prof.Dr. H. Visscher - palynology
Energie Centrum Nederland, Petten
Dr. H.A. van der Sloot - suspended matter
College of Marine Studies, University of Delaware, Lewes, U.S.A.
Dr. G.W. Luther III
Geological Institute, University of Bergen, Norway
Prof.Dr. H. Schrader
Laboratoire d'Oceanographie Dynamique et de Climatologie, Université Pierre et Marie Curie, Paris, France
Dr. C. Vergnaud-Grazzini

Classification

Disciplines and subdisciplines:
geochemistry, chemical oceanography, stratigraphy, paleoceanography, palaeoclimatology, palaeoecology

Areas of application:
variations in productivity in response to climatic change.

3.2. Area and Schedule

Operational programme

A) Transit programme from Victoria across the Somali Basin and the Central Arabian Sea to Karachi. (Figure D.1, area 1).
In this deep water transect a total of 8 stations will be occupied where water and suspended matter will be collected. Furthermore, 8 box cores and 8 piston cores are required from the slopes and abyssal

plains for geochemical purposes. This part of the project will be carried out in conjunction with the operations of project D2 (Depositional Architecture and Sediment Facies of the Middle to Lower Indus Fan).

B) Pakistan region. Paleoceanography and geochemistry (Figure D.1, area 2;).
- A 3.5 kHz acoustic system will be used to help select 2 transects across the Pakistan margin that show minimal sediment disturbance.
- Per transect 6 CTD stations need to be occupied to establish salinity, temperature and oxygen profiles.
- Subsequently along each transect bottom samples will be taken from sites defined by the oxygen profiles and also by morphological and stratigraphic information from the 3.5 kHz profiles. It is suggested to take about 5 box cores from 25 m down to 500 m water depth, another 5 box cores within the OMZ (water depth about 500 to 900 m), and yet another 5 box cores from below the OMZ down to about 3000 m. In addition to the box cores it is planned to take 3 piston cores across the upper depth limit and 2 piston cores from within the OMZ. Duplicate pistoncores have to be raised for geological and geochemical studies.

C) Murray Ridge: Paleoceanography and geochemistry (Figure D.1 area 2).
Site surveying is necessary. Six to eight stations will be occupied and on each station water and suspended matter will be collected from different water depths. Furthermore, on each station one box core and two piston cores (one for geology, one for geochemistry) will be taken.

D) Oman region. Geochemistry (Figure D.1, area 3)
Site surveying time can be kept to a minimum if records obtained on previous legs and on foreign, probably U.S., cruises are available for target identification. Seven stations will be occupied and on each station water and suspended matter will be sampled from different water depths. Furthermore on each station one box core and one piston core of 8-10 m length will be recovered.

E) Owen Ridge. Geochemistry (Figure D.1, area 3)
On one station water and suspended matter will be collected from different depths. Furthermore, at four stations one box core and two piston cores (one for geology, one for geochemistry) will be recovered.

3.3. Methods, Equipment and Facilities

Apart from standard well equipped laboratories, workshops and storage space, standard tools and instruments for sampling and analyses, as required for routine multidisciplinary earth scientific projects aboard R.V. Tyro, there is a specific need for the research projects proposed to carefully monitor the exact water depths where samples were taken. For that specific purpose a 10 to 12 kHz pinger is required which can be clamped on the sampling wire at a discrete distance above the sampling tool. Furthermore it is essential that for trace element sampling and analysis a 'clean' laboratory is available.

3.4. Training and Education

There are provisions to accommodate two scientists/trainees aboard the RV 'Tyro', during operations at sea during leg 1 and four during both leg 2 and leg 3, two from Pakistan and two from Oman, respectively. To have the full benefit of this education it is essential that trainees familiarize themselves thoroughly with methods and techniques during a three months programme at the University of Utrecht, prior to operations at sea. Based on the experience gained in Utrecht and aboard the ship, it is possible that students will be selected to enter a study programme (leading to a MSc or a PhD), in Geochemistry or Palaeontology/Palaeoceanography under supervision of scientists of the University of Utrecht.

4. References

Berner, R.A., 1980 A rate model for organic matter decomposition during bacterial sulfate reduction in marine sediments. In: Biogeochimie de la matiere organique a l'interface eau-sediment marin. Colloq. Int. CNRS 293: 35 - 44.

Boyle, E.A. & L.D. Keigwin 1978 North Atlantic thermohaline circulation during the past 20,000 years linked to high-latitude surface temperature. Nature, 330: 35 - 40.

Bradford, M.R. & D.A. Wall 1984 The distribution of recent organic-walled dinoflagellate cysts in the Persian Gulf, Gulf of Oman and NW Arabian Sea. Paleontographica, B, 192: 16 - 84.

Brinkhuis, H. & W.J. Zachariasse 1988 Dinoflagellate cysts, sea level changes and planktonic foraminifera across the Cretaceous- Tertiary boundary at El Haria, NW Tunisia. Marine Micropal., 13: 153 -191.

Caratini, C., J. Bellet & C. Tissot 1981 Etude microscopique de la matiere organique : palynologie et palynofacies. In: Geochimie organique des sediments marins profonds ORGON IV. Golfe d Aden, Mer d Oman. CNRS, Paris: 265 - 307.

Caratini, C. & C. Tissot 1985 Le sondage Misedor - Etude palynologique. Etud. Geogr. Tropic., 3: 1 - 49.

Cleve, P.T. 1903 Report on plankton collected by M. Thorild Wulff during a voyage to and from Bombay. Ark. Zool. Stockholm., 1: 329 - 381.

Collier, R.W. 1985 Molybdenum in the Northeast Pacific Ocean. Limnol. Oceanogr., 30: 1351 - 1354.

Corliss, B.H. 1985 Microhabitats of benthic foraminifers within deep-sea sediments. Nature, 314: 435 - 438.

Dale, B. 1983 Dinoflagellate resting cysts: benthic plankton. In: G.A. Fryxell (ed.): Survival strategies of the algae. Cambridge Univ. Press: 144 pp.

De Lange, G.J. 1986 Early diagenetic reactions in interbedded pelagic and turbiditic sediments in the Nares Abyssal Plain (Western North Atlantic): consequences for the composition of sediment and interstitial water. Geochim. Cosmochim. Acta, 50: 2543 - 2561.

De Lange, G.J., J.J. Middelburg & P.A. Pruysers 1989 Middle and Late Quaternary depositional sequences and cycles in the eastern Mediterranean. Sedimentology, 36: 151 - 158.

Emerson, S.E. 1985 Organic carbon preservation in marine sediments. In:E.T. Sundquist E.T. & W.S. Broecker (eds):The carbon cycle and atmospheric CO_2: Natural variations Archaen to Present. AGU Geophys. Monogr. Washington

D.C. 32: 78 - 88.
Emerson, S., C. Stump, P.M. Grootes, M. Stuiver, G.W. Farwell & F.H. Schmidt 1987 Estimates of degradable organic carbon in deep-sea surface sediments from ^{14}C concentrations. Nature, 329: 51 - 53.
Fontugny, M.R. & D.C. Duplessy 1986 Variations of the monsoon regime during the Upper Quaternary: evidence from carbon isotopic record of organic matter in North Indian Ocean sediment cores. Paleogeogr. Paleoclimat. Paleoec. 56: 69 - 88.
Harland, R. 1977 Recent and Late Quaternary (Flandrian - Devensian) dinoflagellate cysts from marine continental shelf sediments around the British Islands Paleontographica, B, 164: 87 - 126.
Jorissen, F.J. 1988 Benthic foraminifera from the Adriatic Sea; principles of phenotypic variation. Utrecht Micropal. Bull., 37: 174 pp.
Kolla, V., P.K. Ray & J.A. Kostecki 1981 Surficial sediments of the Arabian Sea Mar. Geol. 41: 183 - 203.
Koske, P.H. 1972 Hydrographische Verhältnisse im Persische Golf auf Grund von Beobachtungen von F.S. Meteor im Frühjahr 1965. Meteor Forsch. Ergeb.. A.11: 58 - 73.
Ledbetter, W. 1977 Abyssal paleocirculation in the Vema Channel (Southwest Atlantic). Ph.D. thesis, Univ. Rhode Island, Kingston.
Marchig, V. 1972 Zur Geochemie rezenter Sedimente des Indische Ozeans. Meteor Forsch. Ergeb. C.11: 1 - 104.
Middelburg, J.J., D. Hoede, H.A. Van der Sloot, C.H. Van der Weijden & J. Wijkstra 1988 Arsenic, antimony and vanadium in the North Atlantic Ocean. Geochim. Cosmochim. Acta 52: 2871 - 2878.
Mix, A.C. & R.G. Fairbanks 1985 North Atlantic surface ocean control of Pleistocene deep-sea circulation. Earth Planet. Sci. Lett. 73: 231 - 243.
Mullins, H.T.,J.B. Thomson, K.McDougall & T.L. Vercoutere 1985 Oxygen Minimum Zone edge effects: evidence from the central Californian coastal upwelling system. Geology, 13: 491 - 494.
Naqvi, S.W.A., R.J. Noronha & C.V. Gangadhara-Reddy 1982 Denitrification in the Arabian Sea. Deep Sea Res. 29: 459 - 469.
Prell, W.L. & E. Van Campo 1986 Coherent response of Arabian Sea upwelling and pollen transport to Late Quaternary monsoonal winds. Nature, 323: 526 - 528.
Prell, W.L. & Scientific Party ODP Leg 117, 1988 Leg 117 finds mountains, monsoons. Geotimes 33 (3): 13 - 15.
Reimers, C.E. 1988 The control of benthic fluxes by particulate supply. In: Productivity of the ocean: present and past. Dahlem Conf. April 1988:
Schott, F. 1983 Monsoon response of the Somali Current and associated upwelling Progr.. Oceanogr. 12: 357 - 381.
Schröder, B. 1906 Beiträge zur Kenntnis des Phytoplanktons warmer Meere. Viertel jahrschr. Nat. Forsch. Ges. Zürich 51: 319 - 377.
Sen Gupta, R. & S.W.A. Naqvi 1984 Chemical oceanography of the Indian Ocean north of the equator. Deep Sea Res. 31: 671 - 706.
Siddiquie, H.N,., A.R. Gujar, N.H. Hashimi & A.B. Valsangkar 1984 Superficial mineral resources of the Indian Ocean. Deep Sea Res.31: 763 - 812.
Siedler,G. 1968 Schichtungs- und Bewegungs Verhältnissen an süd Ausgang des Roten Meeres. Meteor Forsch. Ergeb. A 4: 1 - 76.
Southam, J.R., W.H. Peterson & G.W. Brass 1982 Dynamics of anoxia. Paleogeogr. Paleoclimat. Paleoec. 40: 183 - 198.
Swallow, J.C. 1984 Some aspects of the physical oceanography of the Indian Ocean Deep Sea Res.31: 639 - 650.
Thierstein, H.R. 1988 Inventory of paleoproductivity records: the mid- Cretaceous enigma. In: Productivity of the ocean: present and past. Dahlem Conf. April 1988:
Tschernia, P. 1980 Descriptive regional oceanography. Pergamon Press: 253 pp.
Turner, D.R., M. Whitfield & A.G. Dickson 1981 The equilibrium speciation of dissolved components in freshwater and seawater at 25 C and 1 atm. pressure. Geochim. Cosmochim. Acta: 855 - 882.
Van Campo, E., J.C. Duplessy & M. Rossignol Strick 1982 Climatic conditions deduced from a 150 kyr oxygen isotope-pollen record from the Arabian Sea Nature, 296: 56 - 59.
Verhallen, P.J.J.M. 1987 Early development of Bulmina marginata in relation to

paleoenvironmental changes in the Mediterranean. Proc. Kon. Ned. Akad. Wet. B, 90: 161 - 180.
Von Stackelberg, U. 1972 Faziesverteilung in Sedimenten des Indisch-Pakistanischen Kontinentalrandes (Arabisches Meer). Meteor Forsch. Ergeb. C: 1 - 73.
Wall, D., B. Dale, G.P. Lohmann & W.K. Smith 1977 The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the North and South Atlantic Ocean and adjacent seas. Marine Micropal. 2: 121 - 200.
Warren, B.A. 1981 Transindian hydrographic section at Lat. 18 S: property distributions and circulation in the South Indian Ocean. Deep Sea Res. 28: 759 - 788.
Wilson, T.R.S., J. Thompson, D.J. Hydes, S. Colley, F. Culkin & J. Sorensen 1986 Oxidation fronts in pelagic sediments: diagenetic formation of metal-rich layers. Science 232: 972 - 975.
Wyrtki, K. 1971 Oceanographic atlas of the International Indian Ocean Expedition. Nat. Sci. Found., U.S. Govt. Print. Office: 531 pp.
Wyrtki, K. 1973 Physical oceanography of the Indian Ocean. In: B. Zeitschel (ed.): Ecological studies, analysis and synthesis, 3 Springer (New York, Berlin): 18 - 36.

D2 Sedimentation of the Indus Fan

1. Introduction

The internal structure and development of submarine fan systems, specifically their distal parts, are not understood in detail. Since submarine fans are potentially important hydrocarbon reservoirs, the study of these systems should help establish models for their exploration. The present study entails the analysis of the internal structure of the Indus Fan by high resolution seismic profiling and by taking sediment cores from fan channels, channel levees and sheet deposits.

2. Scientific Rationale

Detailed facies relationships of different portions of submarine fans in general and of the Indus fan in particular are still relatively poorly known (Stow & Piper, 1984; Kolla & Coumes, 1987). A better knowledge of these facies is important for two reasons:

a)Detailed facies analysis aids in developing interpretations of hydrodynamic processes that shape submarine fans.

b)Sequence stratigraphic concepts predict that most of the future hydrocarbon reserves will be found in Lowstand Systems Tracts LST's), which consist primarily of submarine fan systems. Thus, a better and more detailed understanding of submarine fan facies will aid reservoir geologists in developing models for exploration.

The most recent summary of the sedimentology and stratigraphy of the Indus fan is by Kolla & Coumes (1987). These authors stated that sediments of the upper fan are finer-grained than those of the lower fan, which have a higher proportion of sand-silt beds than those of the upper fan. Sedimentation on the lower fan was predominantly by both channelized and unchannelized turbidity currents during lowstands of sea level (Figure D2.1). Thus, about 30% of its surface contains numerous small channels, with or without levees (20 m or less in height). The lower fan extends to depths greater than 4600 m, has gradients of less than 1:1000 and contains channels with width to depth ratios greater than 60. Different types of Bouma sequences have been observed in varying abundance in piston cores in this part of the fan (Figure D2.2).

Kolla & Coumes' (1987) work on the Indus fan, as well as that of others on different submarine fans has left a number of questions for future research. Some of these questions relate to the sedimentary facies of channels on submarine fans: for example, the postulated grain-size distribution in submarine fan channels has largely been derived from existing fluvial models and is to date insufficiently tested on modern fans (Bouma et al., 1985). In relation to this, the nature of submarine channel fill is largely unknown. Do these channels fill predominantly by bank collapse (i.e. by sediment failure-type processes) or by in-channel sedimentation (i.e. by turbidity currents;Bouma et al., 1985)?

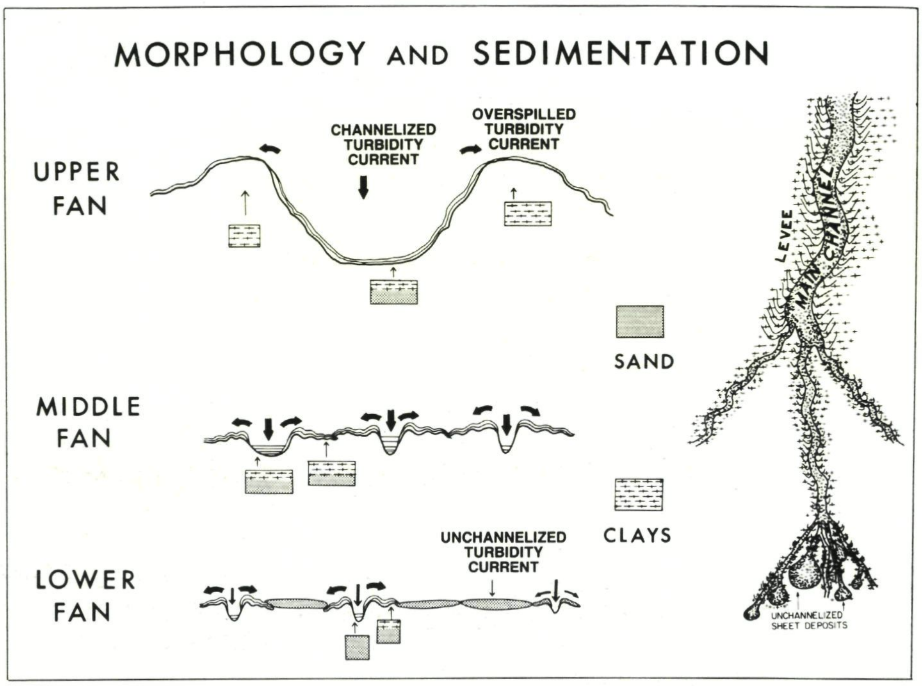


Figure D2.1: Model of sedimentation for Indus Fan. Left-hand side of figure shows decreasing influence of channelized and overbank turbidity currents and increasing influence of unchannelized currents with increase in sand lithology from upper to lower fan. Right-hand side of figure depicts morphology, and apparent branching in middle and lower fan may be due to channel abandonment and avulsion and/or actual branching. (From Kolla & Coumes, 1987).

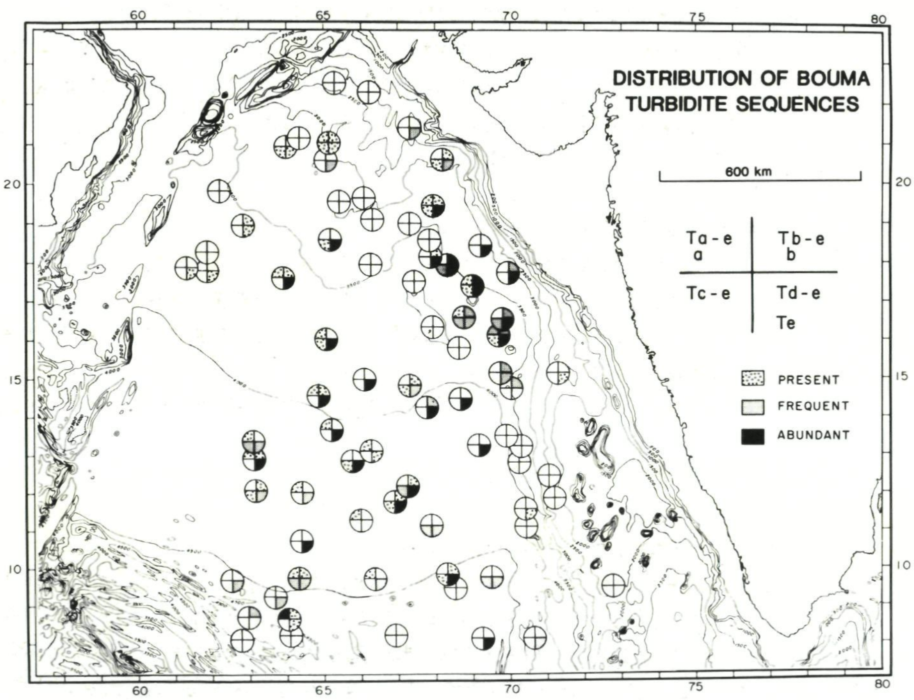


Figure D2.2. Distribution of turbiditic sequences (Bouma, 1985).

3. Project Specifics

3.1. Participants and Classification

Project management:
Dr. W.J.M. van der Linden
Working Group Marine Earth Sciences
Faculty Geology & Geophysics
University of Utrecht, The Netherlands

Participating institutes and responsible scientists:
Institute of Earth Sciences, University of Utrecht
Dr. E.C. Kosters - sedimentology
Dr. W.J.M. van der Linden - acoustics, site surveys
National Institute of Oceanography, Karachi, Pakistan.
Dr. Asif Inam
Department of Oceanography, University of Southampton, U.K.
Dr. D.A.V. Stow - sedimentology

Classification
Disciplines and subdisciplines:
sedimentary geology, stratigraphy
Areas of application:
hydro carbon exploration, evaluation of reservoir characteristics

3.2. Area and Schedule

In areas selected from existing side-scan images a detailed site survey is required to pinpoint coring targets in channels and in turbidite lobes. To that end a carefully monitored, 3.5 kHz box-line survey will be executed requiring the better part of 2 days. Actual sampling operations demand careful manoeuvring of the sampling tool (the corer) over the sampling site. This will be achieved by clamping a 10 or 12 kHz pinger on the wire at a discrete distance (50 m) above the corer. In this way the exact distance of the corer over the bottom can be monitored with accuracy even in waterdepths of several thousand metres. With the corer hanging at a safe distance over the bottom the vessel will be manoeuvred (upstream and upwind) in such a way that when the final approach to target is made, the corer will slowly drift over the site. For accurate positioning of the vessel over the sampling sites and for the coring operation itself a total of three days is required. This project will be carried out in conjunction with the Somali Basin to Karachi transect programme of project D1 (Late Quaternary Productivity and the Dynamics of the Oxygen Minimum Zone) in area 1 (Figure D1).

3.3. Methods, Equipment and Facilities

An attempt to begin answering the questions set out in the Scientific Rationale can be made by acquiring sediments from channels on the lower Indus fan in around 4000 m waterdepth. Sediments should be recovered by means of piston coring and box coring in two transects. Per transect a minimum of about five piston cores, each about 8-10 m in length, and four box cores are required to provide sufficient material. Piston cores will be examined using standard sedimentologic logging techniques, X-ray radiography, and grain size and clay mineral analyses. In addition, thin-sections will be prepared in order to examine petrographic characteristics of the sedimentary column.

Location of piston cores will be determined using existing side-scan sonar data. These exist at the Institute of Ocean Sciences, Wormley, U.K. In addition, recent cruises from the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven and from the Lamont Doherty Geological Observatory in New York have been in the area. Apart from the regular coring tools it is essential that a 10 or 12 kHz pinger is available that can be clamped on the coring wire. Furthermore, to properly execute the sampling operation, the identification of sampling sites must be carried out in close communication with the ship's navigator (officer of the watch). This makes it imperative that during those operations waterdepths are monitored with the ship's echo sounder and with an EPC (slave) recorder both installed on the bridge.

3.4. Training and Education

There are provisions to accommodate four scientists/trainees aboard the RV 'Tyro'. To have the full benefit of this education it is essential that trainees familiarize themselves thoroughly with methods and techniques during a three months programme at the University of Utrecht, prior to operations at sea.

4. References

Bouma, A.H., W. Normark & N. Barnes, 1985 - Submarine fans and related turbidate systems. Springer Verlag: 245 p.

Kolla, V. & F. Coumes, 1987 - Morphology, internal structure, seismic stratigraphy, and sedimentation of the Indus Fan. Bulletin American Association of Petroleum Geologists, vol. 71, no. 6: 650-677.

Stow, D.A.V. & D.J.W. Piper, 1984 - Deep-water fine-grained sediments: facies models. In: Stow, D.A.V. & D.J.W. Piper, 1984, Fine-grained sediments: Deep-water processes and facies. Geological Society, Spec. Publ. no. 15: 611-646.

E

Biology of Oceanic Reefs

1. Introduction

The study of ecology and biogeography of tropical benthic systems performed by Dutch research teams is currently directed primarily towards coral reefs and related ecosystems. Research groups of the National Museum of Natural History (NNM), Leiden, the Institute of Taxonomic Zoology (ITZ), University of Amsterdam, the Delta Institute for Hydrobiological Research (DIHO), Yerseke, the Netherlands Institute for Sea Research (NIOZ), Den Burg, Texel and the Department of Marine Biology of Groningen University have long-term research projects in a few areas (notably Indonesia and the southern Caribbean), where in-depth studies are made of the local ecosystems. In addition several marine expeditions (e.g. with Luymes, Tydeman and Tyro) were made to tropical and subtropical areas (Caribbean, West Africa, Indonesia), where the results of long-term studies were tested in a great variety of environments. Foreign institutes and universities (e.g. from Australia, Belgium, Colombia, Indonesia, Netherlands Antilles and the USA) participate in these projects.

In these investigations comparative research in a high oceanic area is now a high scientific priority. A series of coherent studies are proposed, which centre on the question of interocean variability of reef properties. Differences and similarities observed between non-oceanic regions such as Indonesia and the Caribbean may reflect e.g. prolonged separate histories and local circumstances. An expedition to an oceanic region, which is pristine for a considerable part (such as the Seychelles) may contribute to answering some fundamental questions, because of the proximity and shared history with the Indo-West Pacific convergence area and a similar diversity on the one hand and the lack of continental influences on the other hand.

2. Scientific Rationale

For a better understanding of the highly complex tropical marine biota multidisciplinary long-term in-depth studies are indispensable. Typically this is the type of work being done in field stations. However, a disadvantage is that only a restricted number of the diverse biota can be studied. Because of local circumstances generalizations are often unwarranted (Birkeland, 1987a, b).

In the only general textbook on tropical marine ecology (Longhurst & Pauly, 1987) attention is drawn to the unbalanced development of tropical marine benthology. The main reasons seem to be that most research projects are restricted to certain areas and to certain disciplines, and that the conceptual framework is not always well developed (van der Land, 1989). Interdisciplinary projects with a wide scope, as well as geographically comparative, are needed. Ship-based expeditions can be extremely useful for this purpose but they are rare nowadays (van der Land & Soekarno, in press).

Coral reef fisheries are generally considered to be an important source of food and income in many tropical coastal regions. However, the nature of these fisheries is not always understood rightly, which may result in management problems. A nomenclatorial problem is that the term coral reef is used in several different ways (van der Land, 1989): fisheries biologists tend to use it in a geomorphological sense; conservationists tend to use it for scleractinian dominated benthic communities. Of course this may lead to different views on management policy. The term coral reef fishery often results in misunderstanding. It does not mean fishing for coral reef fishes. In the first place there are very few genuine coral reef fishes (already stressed by Abel, 1972), in the second place most species are not restricted to certain bottom communities (Polunin, 1984; Martosewojo, 1989) and in the third place it may well be that in general only pelagic or coastal pelagic fishes are really important for reef fishermen, as was found out in Indonesia (ter Kuile, 1989). It would be of interest to determine if commercial fisheries on oceanic islands like the Seychelles is or could in principle be more or less restricted to tapping pelagic resources, as is the case in Indonesia. The same may hold for recreational fisheries, which gradually could become more important (as e.g. on the Great Barrier Reef, where this type is economically more important).

A detailed account on Seychelles fisheries is given by Polunin (1984). The human impact on natural resources is treated by Stoddart (1984b) and Wells (1988), not to mention several recent reports on fisheries and conservation, mostly unpublished and difficult to trace.

2.1. Biogeography

Many marine benthic species are distributed throughout the Indo-Pacific and for that reason this whole area is often regarded as a single marine biogeographic region. It was e.g. treated as such by lack of sufficient data on the Indian Ocean by ten Hove et al. (in press). Local endemism certainly occurs in the Indo-Australian region and in the Red Sea, but other peripheral areas are suspect areas of endemism. It has been suggested (e.g. by Briggs, 1974; Vacelet et al., 1976; Rosen, 1975) that the Western Indian Ocean has its own endemic species. However, doubts are justified (Hoeksema, 1989) because reports on endemism are mostly based on comparison of the Western Indian Ocean specimens with descriptions in the literature or museum specimens. Sheppard (1987) made an effort to sort out the references to the hermatypic corals of the Indian Ocean and could recognize geographical groupings by cluster analysis. A comprehensive review of these biogeographic problems and the present status of our knowledge is given by Rosen (1988).

The research group involved has a unique experience in that most participants recently gained first-hand knowledge of the Indonesian fauna in the field (in addition ample colour photographs and video-images of live specimens from Indonesian reefs are available). Now there is an opportunity to compare selected genera and species of several groups of reef organisms (including algae, sea grasses, sponges, actiniarians, corals, serpulids, crustaceans, molluscs and echinoderms) from the Central Indian Ocean with those of the Indo-West-Pacific. The choice of representatives of several animal and plant groups guarantees that conclusions are not hampered by group-related peculiarities. It is quite helpful that at least some groups of benthic organisms are reasonably well known, e.g. fishes (Polunin, 1984; Smith & Smith, 1969), echinoderms (Clark, 1984), decapods (Garth, 1984; Bruce, 1984), molluscs (Taylor, 1968, 1971) and scleractinians (Rosen, 1971; Pillai et al., 1973; Wijsman Best et al., 1980). On the other hand little is known of certain other important groups such as algae, polychaetes and octocorals.

The fact that symbionts of sedentary hosts have minor possibilities for dispersal, may promote endemism as has been observed in actinian-associated clown fishes (*Amphiprion*). Endemic species of this group are present in various relatively isolated archipelagoes and limited areas, including the Seychelles. The fact that twin species in *Amphiprion* occur on both sides of the area from Malaya to Australia may be explained by the fact that this area was an almost complete land-barrier in the Pleistocene (about 1.6 million years ago). It will be tried to determine whether the same phenomenon occurs in crustacean symbionts of actiniarians by comparing observations in Indonesia with material from the Indian Ocean. The fact that in this respect a considerable amount of basic information on the Seychelles fauna is available facilitates such studies (see Bruce, 1984, for shrimps and Garth, 1984, for brachyurans). The study of life specimens and in-situ colour photographs is essential for a determination of the slight differences to be expected.

Is the relatively young age of most oceanic island biota reflected by the composition of their deep water fauna? It is well-known that pre-Tethyan (?) reef-building organisms such as Lithistid sponges and vermetid molluscs persist in slope localities beyond modern reef habitats in areas of considerable age (e.g. Bahamas, Pomponi & Diaz, pers. comm.; Barbados, Van Soest & Stentoft, 1988); New Caledonia, Lévi & Lévi, 1983; many Indonesian localities, Siboga and Snellius-II collections). From those observations one would expect the pre-Tethyan deep-water elements to be absent from oceanic islands, since the organisms concerned show a low dispersal capacity. We do not expect that the granitic Seychelles, considered to be a separate microcontinent since the early Tertiary, have given elements of an old fauna a possibility to survive, but of course there is a possibility. The occurrence of the famous relic *Latimeria* near the Comores is possibly not unique. The basic continental rocks, derived from Gondwanaland, are of pre-Cambrian age, but little is known about the marine biological history of the region (Brainwaithe, 1984). Deep water observations will be made by dredging on the platform and the slopes at depths between 20 and 75m and at about 100m, 200m and-500m at several localities. This is also important because there have been few dredging expeditions in the area, so relatively little is known about the benthic fauna and flora at depths greater than 20 m, i.e., the greater part of the Seychelles and Amirante banks.

2.2. Autoecology

It will be tried to determine the distribution, relative to depth, exposure and bottom morphology, of a number of dominant or otherwise important sessile organisms of several groups, e.g. sponges, actinians, soft corals, scleractinians (e.g. *Faviidae*, *Fungiidae*), echinoderms, algae, seagrasses. This approach, independent of subjectively chosen communities has been proven to be valuable for a better understanding of benthic biota. Nutrient availability, itself depending on several other factors, is a major determining factor for benthic distributions (Wilkinson, 1986; Birkeland, 1987b). The study of certain species may be an effective tool for practical ways of reef monitoring as was shown by Moll (1986). Such studies should not be restricted to certain types of animals (scleractinians are often used), but should include a variety of organisms, including e.g. sponges and seagrasses (Nienhuis et al., 1989). Within species due attention should be given to the occurrence of ecomorphs.

The occurrence of certain types of symbiosis (including commensalism and parasitism will be studied, particularly the symbiotic relationships between prawns, fishes (*Amphiprion*) and actiniarians. If feasible host specificity will be studied by experiments with *Actinodendron* and *Cryptodendrum*, to determine why certain symbionts prefer a certain range of hosts species. This is probably related not only to the general morphology but also to the type of cnidom of the hosts.

2.3. Reef Structure and Ecology

Various reef models and generalities were formulated which should be tested under ideal circumstances such as those of oceanic islands. These include hypotheses about the influence on reef composition and productivity of (1) abiotic factors such as distance from river outflow, exposure and sedimentation, (2) biological factors such as availability of larval supply from neighbouring reefs, growth form and biochemical properties as survival factors, and predation and competition for space, and (3) geological factors such as the history of sea level fluctuations and age of the reef base. The research aims at testing such hypotheses by carrying out systematic transect-type of observations of the composition of marine biota of selected reefs. The Seychelles region is well suited for this type of research because of the presence of a wide variety of coastal environments, from high islands with an old base to open sea reefs, from exposed to sheltered situations, from highly disturbed or exploited to pristine areas. Because of the short time available only a restricted number of transects can be studied and they have to be recorded on video.

The role of phototrophic organisms on reefs is important. Since available information shows that at least part of the reefs of the Seychelles are exposed and devoid of terrigenous sediment, it is expected that the dominant life forms are zooxanthellate corals, calcareous algae and autotrophic sponges (*Phyllospongia*) (e.g. Wilkinson, 1987), and that spatial competition from heterotrophs (Alcyonarians, heterotrophous sponges) is weak. This would support various hypotheses concerning the crucial role of sedimentation in structuring reef composition and productivity. The results of Indian Ocean transects can be compared with data from other areas such as Eastern Indonesia, the Great Barrier Reef and the Caribbean.

Detailed hypotheses about the relationship of exposure gradients and physiognomic-structural attributes of reefs (Bak & Povel, 1989) or occurrence of certain taxa (e.g. Hoeksema, 1989, Hoeksema & Moka, 1989; van Soest, 1989; Wilkinson, 1987) will be tested outside their centre of diversity (in this case Indonesia and Australia). A most interesting question is whether the physiognomical method is superior to that of the taxonomic method, thereby introducing a biogeographical angle which is unexplored to date. These hypotheses can be tested by using the results of transect observations.

Are allelopathic interactions in Indian Ocean reef organisms comparably frequent and important as a structuring force as in the Indo-West Pacific? From the number of studies describing allelopathic (frequently anti-biotic, anti-fungal or anti-viral) compounds isolated from reef organisms, it is clear that Indo-West Pacific benthic organisms (notably alcyonarians and sponges) produce these compounds more frequently and more diversely than do comparable organisms in the Atlantic (Braekman, pers. comm.). Before embracing the theory that Atlantic benthic organisms somehow lost the need or the ability to synthesize such compounds, it should be tested whether the isolated islands of the Indian Ocean harbour organisms as prolific in their biochemistry as those from Micronesia, North East Australia and S. Japan. Methods include collecting and extracting (or deep-freezing) reef organisms; further processing will be done in Brussels.

2.4. Collection

Much material will be obtained of groups of animals and plants which, according to the programme and because of the available man-power, can not be worked up. This applies particularly to material sampled in deep water with grabs, dredges and trawls and to the smaller infauna, which can hardly or not at all be observed in the field. The sampling will consequently result in collections of considerable size that will form a valuable source of material for future studies, as a follow-up of the main project.

3. Project Specifics

3.1. Participants and Classification

Project management

Dr. J. van der Land
National Museum of Natural History,
P.O. Box 9517, 2300 RA Leiden
tel. 071-143844

Dr. R.W.M. van Soest
Institute of Taxonomic Zoology
P.O. Box 4766, 1009 AT Amsterdam
tel. 020-5255422

Participating institutes and responsible scientists:

National Museum of Natural History (NNM), Leiden
zootaxonomy, biogeography, ecology, education
M.R.R.B. Best
C.H.J.M. Fransen
J.C. den Hartog
J. van der Land
M.J.P. van Oijen
Institute of Taxonomic Zoology (ITZ), University of Amsterdam
zootaxonomy, biogeography, ecology
H.A. ten Hove
R.W.M. van Soest
National Herbarium, Leiden (NHL)
W.F. Prud'homme van Reine - algology, biogeography
Delta Institute for Hydrobiological Research (DIHO), Yerseke
P.H. Nienhuis - seagrass ecology
Netherlands Institute for Sea Research (NIOZ), Den Burg, Texel
ecology, cartography
R.P.M. Bak
F.C. van Duyl
Institute for Earth Sciences, Free University, Amsterdam
G.J. Boekschoten - paleontology
Laboratory of Marine Biology (LMB), Free University, Brussels
C. DeRidder - ecology, biochemistry

Classification

Disciplines and subdisciplines:
biology (zoology, botany): biogeography, taxonomy, ecology, benthology

Areas of application:
fisheries; coastal zone management; environmental education

3.2. Area

The research programme is planned to take place in the area of the Seychelles and Amirante Islands. The research described here should take place far away from any continental influence. The Seychelles are situated on a platform in the central Indian Ocean (Figure E.1), which means that the area has a key position from a biogeographic point of view, between the Indo-Pacific convergence, the most diverse region in the world, and East-Africa and the Red Sea, also highly diverse areas. This is particularly the case because the continental margin of most of South-Asia (in particular India and Pakistan) is unsuitable for blue-water benthos. The area is practically completely situated outside the region of cyclones (Figure E.2), which eliminates a complicating factor.

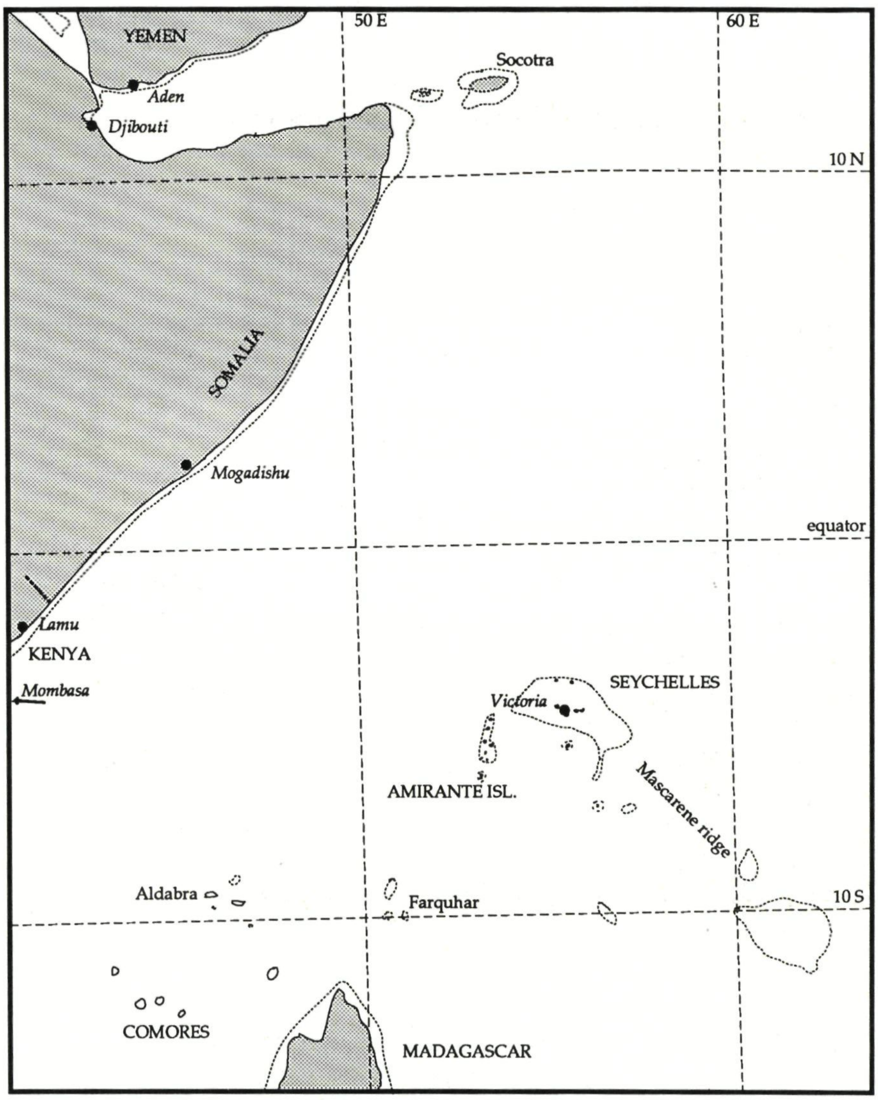


Figure E.1. Geography of the research area

Another reason why the Seychelles were chosen as a research area is that its marine biota are not yet well known. In his review paper on coral reefs of the Seychelles Stoddart (1984a) states: 'The reefs of

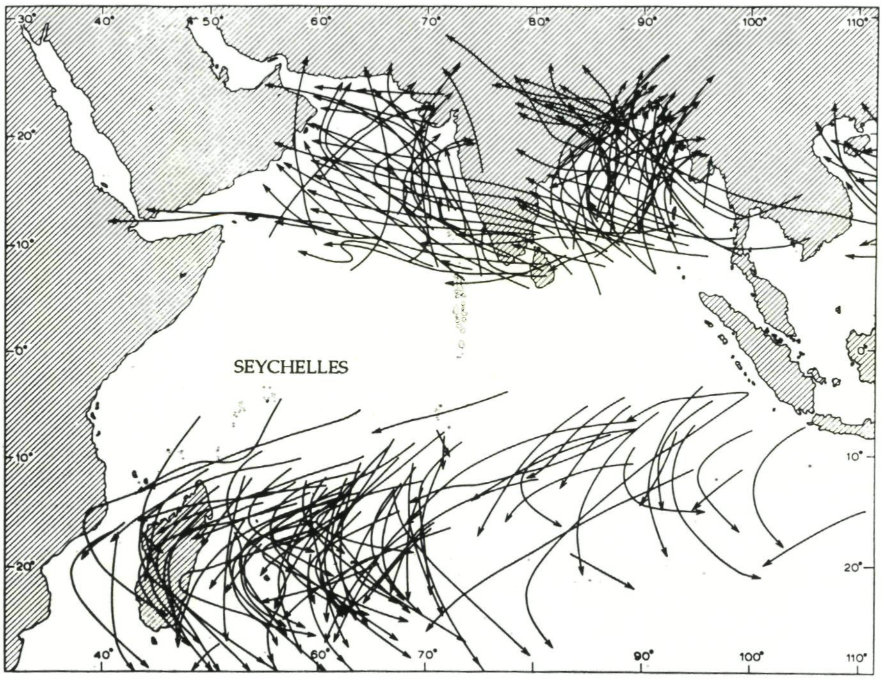


Figure E.2.. Tracks of cyclones in the Indian Ocean

the Seychelles and adjacent areas of the western Indian Ocean are still among the least well-known, though most extensive, of the reefs of the world' and concludes: 'It is clear from this account that a great deal of work needs to be done before the reefs of the Seychelles can be described as adequately known.' Recently several studies were made by US and USSR groups but the results are as yet unpublished. From the available accounts (Stoddart, 1972, 1984a; Wells, 1988) it is evident that several different types of reefs are present. Several of these are important for fisheries purposes or interesting for tourists and consequently of economic importance.

The archipelago comprises a number of islands with a granite base in the eastern group and a number of coral islands in the Amirante group (Figure E.3). They offer a number of highly different environments, from exposed to sheltered conditions. In a cruise of a short duration the whole area of the Republic of the Seychelles, West to Aldabra, cannot be crossed. Therefore a choice has to be made from the northernmost islands of the Seychelles proper and the Amirante Islands. This choice will be made according to wishes from the Seychelles government. Of course advantage should be taken from the availability of a research vessel to study remote islands that are least known.

3.3. Schedule

The ship has to sail from Mombasa, where the participants will board, to Victoria harbour, Mahé, Seychelles. From Victoria a single roundtrip of about three weeks through the archipelago, of which a preliminary track chart is given in figure E.4, is envisaged. The exact route will

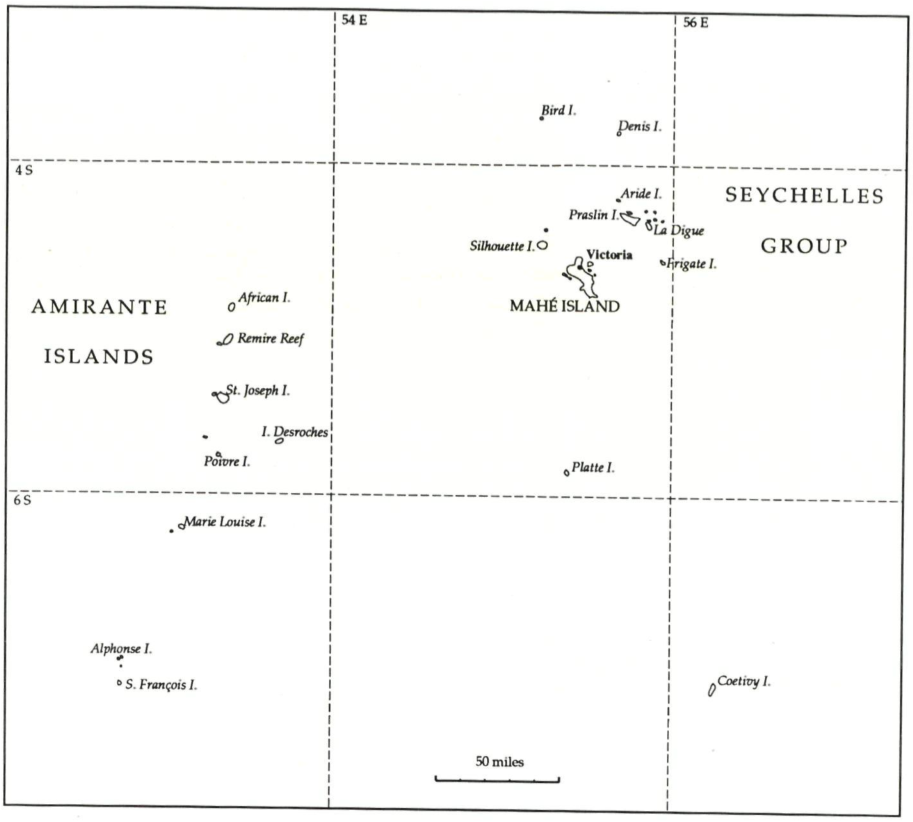


Figure E.3. Topography of the Seychelles Group and Amirante Islands

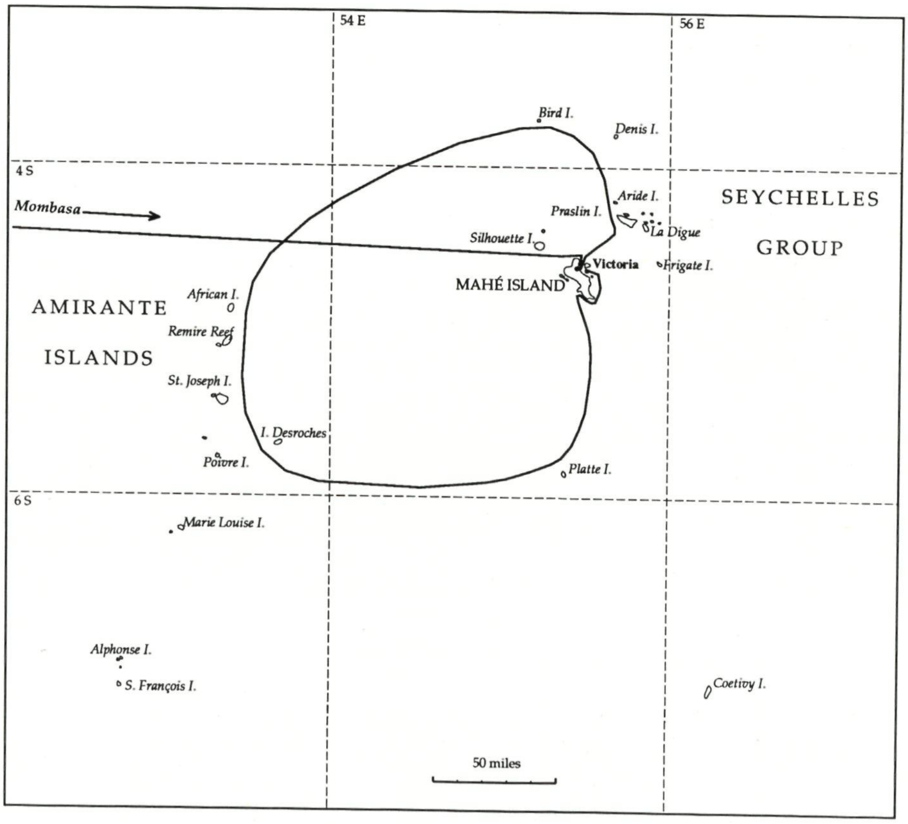


Figure E.4. Preliminary track chart

be determined in consultation with the government of the Republic of the Seychelles. The cruise will end in Victoria and the scientific crew will go back to Europe through Mahé airport.

Fringing reefs along the East and West coasts of Mahé should be studied, because this is the largest, highest and most densely populated island. Of course these reefs are the best-known in the archipelago (e.g. Lewis, 1968, 1969; Rosen, 1971; Taylor, 1968). The reefs of some of the islands NE of Mahé are also important for tourism and several of these are protected in national parks or special reserves.

Bird Island and Denis Island are of interest because these small islands are situated on the edge of the bank, with steep slopes down to the deep sea (Stoddart & Fosberg, 1981). The same holds for Platte Island, but this is isolated from the Seychelles bank, and its reefs have hardly been studied. Desroches (Stoddart & Poore, 1970) and/or St. Joseph (see Stoddart et al., 1979) in the Amirantes should be visited, because they are the only atolls in the area. The latter is considered to be a partly sunken atoll by Stoddart. The African Islands (Stoddart & Poore, 1970b) are very small sand cays but surrounded by extensive reef flats.

In consultation with Seychelles authorities five reef areas will be selected for study, which means that four or five days are available for each.

Since the Netherlands Indian Ocean Programme is going to take place in the period of May 1992 to April 1993 this project has to take place in the period of November 1992 to February 1993, i.e. the period of the NW monsoon. The period of the SE trades has to be avoided

3.4. Methods, Equipment and Facilities

Observations along transects are an important method. Reef profiles will be made by wading, snorkling, SCUBA-diving and, below 50 m, by dredging and trawling, accompanied by measurements of abiotic factors such as submarine light, currents, and sedimentation. It is practically impossible to determine all parameters directly in the field during an expedition of a short duration. Therefore many measurements have to be made later. This can be done by means of photography and particularly by video-recording. A line-transect method will be employed in which photographs and video images will be made of all parts of the transect. The field work will concentrate on the facilitation of the interpretation of the photographic recordings by additional observations and by sampling specimens.

The composition of the benthic communities will be studied in transects (10 m chain and 10 m belts) parallel to the reef gradient at 0-1m, 5m, 10m and 20m depths. Light measurements will be carried out by doing repeated observations with UHIM's at three hours interval at all transect stations. Current velocities will be measured by ink-cloud meters again at three hours interval at all transect stations. Sedimentation will be measured at each locality during three days with wide diameter traps. Autotrophous sponges will be detected by simple field tests (Smit, 1988) and by microscopic examination on board the ship.

The sampling will result in a large number of samples (animals, plants, and sediment). These will be roughly sorted on board and preserved in alcohol or formalin. Part will be macerated (corals) or dried (plants). Certain large specimens will be deep-frozen.

A large amount of equipment will be needed and it is impossible to mention all instruments etc. here. Some important items are:
- About four rubber boats or other small craft.
- Portable, shallow water echo sounder.
- Diving equipment, including at least 20 SCUBA sets.
- Compressor (air-gun compressor can be used for this purpose).
- Underwater cameras, including underwater colour-television camera.
- Diver propulsion vehicles.
- Equipment for drilling in reefs and on land.
- Deep freezing equipment.
- 5 Air-conditioned laboratories.
- Aquaria.
- Bottom grabs (type van Veen), rock dredges.
- Small trawls (Agassiz-trawls 1.2 m, 2.4 m, 3.5 m).
- Several types of traps and nets (including beach seines and gill nets) for the catch of fish etc.
- Neustonnet.
- Electrical saw for the sectioning of limestone blocks and corals.
- X-ray equipment.

3.5. Training and Education

Partly because of the availability of cristal clear water and the relatively undisturbed biota oceanic reef areas are well suited for the collection of educational material (photographs and under-water video). Such material will be collected for a variety of educational products (exhibitions, lectures, videofilms) for different audiences, from students to the general public, which of course is a special task for a natural history museum. Needs for training and education will be explored further in the Seychelles.

4. References

Abel, E.F., 1972. Problem der Ökologischen Definition des "Korallenfisches". Proc. Symp. Corals and Coral Reefs Mar. biol. Ass. India, Cochin: 449-456.

Bak, R.P.M & G.D.E. Povel, 1989. Ecological variables, including physiognomic-structural attributes, and classification of Indonesian coral reefs. Neth. J. Sea Res. 23: 95-106.

Best, M.B., B.W. Hoeksema, W. Moka, H. Moll, Suharsono & I Nyoman Sutarna, 1989. Recent scleractinian coral species collected during the Snellius-II Expedition in eastern Indonesia.Neth. J. Sea Res. 23: 107-115.
Birkeland, C., 1984a. Sources and destination of nutrients in coral reef ecosystems. Unesco Rep. mar. Sci. 21: 3-10.
, (ed.), 1987a. Comparison between Atlantic and Pacific tropical marine coastal ecosystems: community structure, ecological processes, and productivity. Unesco Rep. mar. Sci. 46: 1-262.
, 1987b. Nutrient availability as a major determinant of differences among coastal hard-susbtratum communities in different regions of the tropics. Unesco Rep. mar. Sci. 46: 45-97.
Brainwaithe, C.J.R., 1971. Seychelles reefs: structure and development. In: D.R. Stoddart & C.M. Yonge (eds), Regional variation in Indian Ocean Coral Reefs. Symp. Zool. Soc., London, 28: 39-64.
, 1984. Geology of the Seychelles. In: D.R. Stoddart (ed.), Biogeography and Ecology of the Seychelles Islands. Junk, The Hague: 17-38.
Briggs, J.C., 1974. Marine zoogeography. McGraw-Hill, New York: 1-475.
Bruce, A.J., 1984. Marine caridean shrimps of the Seychelles. In: D.R. Stoddart (ed.), Biogeography and Ecology of the Seychelles Islands. Junk, The Hague: 141-170.
Clark, A.M., 1984. Echinodermata of the Seychelles. In: D.R. Stoddart (ed.), Biogeo graphy and Ecology of the Seychelles Islands. Junk, The Hague: 83-102.
Done, T.J., 1983. Coral zonation, its nature and significance. In: D.J. Barnes (ed.). Perspectives on coral reefs. AIMS, Townsville: 107-147
Duyl, F.C. van, 1986. Reef Cartography in Indonesia (report in pursuance of the Snellius II expedition in 1984). RMNH, Leiden: 1-62.
Fagerstrom, J.A., 1987. The evolution of reef communities. John Wiley, New York [etc.]: i-xv, 1-600.
Garth, J.S., 1984. Brachyuran decapod crustaceans of coral reef communities of the Seychelles and Amirante Islands. In: D.R. Stoddart (ed.), Biogeography and Ecology of the Seychelles Islands. Junk, The Hague: 103-122.
Hoeksema, B.W., Taxonomy, phylogeny and biogeography of mushroom corals. Zool. Verh., Leiden, 254: 1-295.
Hoeksema, B.W. & W. Moka, 1989. Species assemblages and phenotypes of mush room corals (Fungiidae) related to coral reef habitats in the Flores Sea. Neth. J. Sea Res. 23: 149-160.
Hove, H.A. ten, F. Hiemstra & R.W.M. van Soest (in press). Towards a phylogeny of the genus Hydroides (Fam. Serpulidae). In: Proc.3rd Internat. Polychaeta Conf..Bull. Mar. Sci. (1991)
Kuile, C. ter, 1989. The forage base of some reef fishes in the Flores Sea with notes on sampling and fishery. Neth. J. Sea Res. 23: 171-179.
Land, J. van der, 1989. The need for new concepts in reef biology. Neth. J. Sea Res. 23: 231-238.
Land, J. van der & R. Soekarno (in press). Coral reef research of the Indonesian-Dutch Snellius-II Expedition. In: Proc. IOC-WESTPAC Symp. "The Indo-Pacific Convergence", Townsville, 1986.
Lévi, C. & P. Lévi, 1983. Démosponges bathyales récoltées par le N/O "Vauban" au sud de la Nouvelle Calédonie. Bull. Mus. nat. Hist. nat., Paris, (4)5(A,4): 931-997.
Lewis, M.S., 1968. The morphology of the fringing coral reefs along the east coast of Mahé, Seychelles. J. Geol. 76: 140-153.
, 1969. Sedimentary environments and unconsolidated carbonate sediments of the fringing coral reefs of Mahé, Seychelles. Mar. Geol. 7: 95-127.
Lewis, M.S. & J.D. Taylor, 1966. Marine sediments and bottom communities of the Seychelles. Phil. Trans. Roy. Soc. London, A259: 279-290.
Lindeboom, H.J. & A.J.J. Sandee, 1989. Production and consumption of tropical seagrass fields in eastern Indonesia measured with bell jars and microelectrodes. Neth. J. Sea Res. 23: 181-190.
Longhurst, A.R. & D. Pauly, 1987. Ecology of Tropical Oceans. Academic Press, San Diego, etc.: i-xi, 1-407.
Martosewojo, S., 1989. Comparison of the fish communities of the reef flat, the reef edge and the pelagic system in Flores Sea coral reefs. Neth. J. Sea Res. 23: 191-195.
Moll, H., 1983. Zonation and diversity of Scleractinia on reefs off S.W. Sulawesi,

Indonesia. Thesis Leiden Univ.: 1-107.
, 1986. The coral community structure on the reefs visited during the Snellius II Expedition in Eastern Indonesia. Zool. Meded., Leiden, 60: 1-25, fig. 1-7, tbl. 1-10.
Nienhuis, P.H., J. Coosen & W. Kiswara, 1989. Community structure and biomass distribution of seagrasses and macrofauna in the Flores Sea, Indonesia. Neth. J. Sea Res. 23: 197-214.
Piggott, C.J., 1961. Notes on some of the Seychelles Islands. Atoll Res. Bull. 83: 1-10.
Pillai, C.S.G., P.J. Vine & G. Scheer, 1973. Bericht über einen Korallensammlung von den Seychellen. Zool. Jahrb. Syst. 100: 451-465.
Polunin, N.V.C., 1984. Marine fishes of the Seychelles. In: D.R. Stoddart (ed.), Biogeography and Ecology of the Seychelles Islands. Junk, The Hague: 171-192.
Potts, D.C., 1983. Evolutionary disequilibrium among Indo-Pacific corals. Bull. mar. Sci. 33: 619-632.
Proctor, J., 1973. National Parks in the Seychelles. Biol. Cons. 5: 153-155.
Rosen, B.R., 1971. Principle features of reef coral ecology in shallow water environ ments in Mahé, Seychelles. In: D.R. Stoddart & C.M. Yonge (eds), Regional variation in Indian Ocean Coral Reefs. Symp. Zool. Soc., London, 28: 163-184.
, 1971a.The distribution of reef coral genera in the Indian Ocean. In: D.R. Stoddart & C.M. Yonge (eds), Regional variation in Indian Ocean Coral Reefs. Symp. Zool. Soc., London, 28: 263-299.
, 1975. The distribution of reef corals. Reps. Underwater Ass. 1(n.s.): 1-16.
, 1988. Progress, problems and patterns in the biogeography of reef corals and other tropical marine organisms. Helgol. Meeresunters. 42: 269-301.
Russ, G., 1984. A review of coral reef fisheries. Unesco Rep. mar. Sci. 27: 74-92
Salm, R.V., 1983. Reefs of the Western Indian Ocean: a threatened heritage. Ambio 12: 349-353.
Sheppard, C.R.C., 1987. Coral Species of the Indian Ocean and Adjacent Seas: A Synonymized Compilation and Some Regional Distribution Patterns. Atoll Res. Bull. 307: 1-32.
Smit, N., 1988. A survey of sponge-algae associations in the Darwin harbour region (Northern Territories, Australia): 1-95. (student's report)
Smith, J.L.B., & M.M. Smith, 1969. Fishes of the Seychelles, 2nd ed., Smith Inst., Grahamstown: 1-223.
Soest, R.W.M. van, 1989. The Indonesian sponge fauna: a status report. Neth. J. Sea Res. 23: 223-230.
Soest, R.W.M. van & N. Stentoft, 1988. Barbados deep water sponges. Stud. Fauna Curacao Caribb. Isl. 70: 1-175.
Stoddart, D.R., 1967, Summary of the ecology of coral islands north of Madagascar (excluding Aldabra). Atoll Res. Bull. 118: 53-61.
, 1971. Geology and morphology of reefs. In: D.R. Stoddart & C.M. Yonge (eds), Regional variation in Indian Ocean Coral Reefs. Symp. Zool. Soc., London, 28: 3-38.
, 1972. Coral reefs of the Indian Ocean. Regional variation in Indian Ocean coral reefs Proc. Symp. Corals and Coral Reefs Mar. biol. Ass. India, Cochin: 155-174.
, 1984a. Coral reefs of the Seychelles and adjacent regions. In: D.R. Stoddart (ed.), Biogeography and Ecology of the Seychelles Islands. Junk, The Hague: 63-81.
, 1984b. Impact of man in the Seychelles. In: D.R. Stoddart (ed.), Biogeography and Ecology of the Seychelles Islands. Junk, The Hague: 641-654.
Stoddart, D.R. & M.J. Coe, 1979. Geography and ecology of D'Arros Island. Atoll Res. Bull. 223: 3-18.
Stoddart, D.R, M.J. Coe & F.R. Fosberg, 1979. D'Arros and St.Joseph, Amirante Islands. Atoll Res. Bull. 223: 3-18.
Stoddart, D.R, & F.R. Fosberg, 1981. Bird and Denis Islands, Seychelles. Atoll Res. Bull. 252: 1-50.
Stoddart, D.R, & M.E.D. Poore, 1970. Geography and ecology of Desroches. Atoll Res. Bull. 136: 155-165.
Stoddart, D.R, & M.E.D. Poore, 1970a. Geography and ecology of Remire. Atoll Res. Bull. 136: 171-181.
Stoddart, D.R, & M.E.D. Poore, 1970b. Geography and ecology of African Banks. Res.

Bull. 136: 187-191.
Taylor, J.D., 1968. Coral reef and associated communities (mainly molluscan) around Mahé, Seychelles.Proc. Royal Soc. London B254: 129-206
, 1971. Reef Associated Molluscan Assemblages in the Western Indian Ocean. In: D.R. Stoddart & C.M. Yonge (eds), Regional variation in Indian Ocean Coral Reefs.Symp. Zool. Soc., London, 28: 501-534.
Vacelet, J., P. Vasseur & C. Lévi, 1976. Spongiaires de la pente externe des récifs coralliens de Tuléar (sud-ouest de Madagascar). Mém. Mus. nat. Hist. nat., Paris (A, Zool.) 99: 1-116.
Vine, P.J., 1972. Coral reef conservation around the Seychelles, Indian Ocean.Biol. Cons. 4: 304-305.
Walbran, P.D. et al., 1989. Crown-of-thorns starfish outbreaks on the Great Barrier Reef: a geological perspective based upon the sediment record. Coral Reefs 8: 67-78.
Walsh, R.P.D., 1984. Climate of the Seychelles. In: D.R. Stoddart (ed.), Biogeography and Ecology of the Seychelles Islands. Junk, The Hague: 39-62.
Warman, S. & D. Todd, 1984. A biological survey of Aride Island Nature Reserve, Seychelles. Biol. Cons. 28: 51-71.
Wells, S.M., 1988. Coral Reefs of the World. Volume 2: Indian Ocean, Red Sea and Gulf. UNEP/IUCN: i-xlix, 1-389.
Wiebe, W.J., 1987. Nutrient pools and dynamics in tropical, marine coastal environments, with special reference to the Caribbean and Indo-West Pacific regions. Unesco Rep. mar. Sci. 46: 19-42.
Wijsman-Best, M., G. Faure & M. Pichon, 1980. Contribution to the knowledge of the stony corals from the Seychelles and eastern Africa. Rev. zool. Afr. 94: 600-627.
Wilkinson, C.R., 1986. The nutritional spectrum of coral reef benthos or sponging off one another for dinner. Oceanus 29(2): 68-70, 71-73, 74-75.
Wilkinson, C., 1987. Interocean difference in size and nutrition of coral reef sponge populations. Science 236: 1654-1637.

Annex 1: Indian Ocean Committee

Chairman:	Dr. J. van der Land (NNM)
Secretary:	Dr. J.H. Stel (SOZ)
Co-ordinator:	C.N. van Bergen Henegouw (SOZ/NCZ)
Technical Ass.:	E. van Abs (NIOZ)
Project A:	Prof. dr. C. Heip (DIHO)
	Dr. M.A. Hemminga (DIHO)
Project B:	Dr. M.A. Baars (NIOZ)
	Prof.dr. S. van der Spoel (ITZ)
Project C:	Prof.dr. J.E. van Hinte (GC)
	Dr. Tj.C.E. van Weering (NIOZ)
Project D:	Prof.dr. C.H. van der Weijden (RUU)
	Dr. W.J.M. van der Linden (RUU)
Project E:	Dr. J. van der Land (NMN)
	Dr. R.W.M. van Soest (ITZ)

NNM:	National Museum of Natural History P.O. box 9517 2300 RA Leiden tel: (+31) 71-143844 fax: (+31) 71-133344
SOZ/NCZ:	Netherlands Marine Research Foundation P.O. box 93120 2509 AC The Hague tel: (+31)70-3440780 fax: (+31)70-3832173
NIOZ:	Netherlands Institute for Sea Research P.O. box 59 1790 AB Den Burg, Texel tel: (+31) 2220-69300 fax: (31) 2220-19674
DIHO:	Delta Hydrobiological Research Institute Vierstraat 28 4401 EA Yerseke tel: (+31) 1131-1920 fax: (+31) 1131-3616
ITZ:	Institute of Taxonomic Zoology, University of Amsterdam P.O. box 4766 1009 AT Amsterdam tel: (+31) 20-5255422 fax: (+31) 20-5255802
GC:	Geomarine Center, Free University P.O. box 7161 1007 MC Amsterdam tel: (+31) 20-5483511 fax:)+31) 20-6462457
RUU:	Working Group Marine Earth Sciences University of Utrecht P.O. box 80021 3508 TA Utrecht tel: (+31) 30-535050 fax: (+31) 30-535030

Annex 2: List of Abbreviations

CEC	Commission of the European Communities
CTD	Conductivity Temperature Depth
CZCS	Coastal Zone Color Scan
DIHO	Delta Institute for Hydrobiological Research
DSL	Deep Scattering Layers
DSDP	Deep Sea Drilling Programme
EACC	East African Coastal Current
EC	European Community
FAO	Food and Agriculture Organisation
FAME	Fundamental and Applied Marine Ecology
ICES	International Council for Environmental Sciences
IOE	International Indian Ocean Expedition
IOP	Indian Ocean Programme
ITCZ	Intertropical Convergence Zone
ITZ	Institute of Taxonomic Zoology, University of Amsterdam
JGOFS	Joint Global Ocean Flux Study
KMFRI	Kenya Marine and Fisheries Research Institute
KUN	Catholic University of Nijmegen, The Netherlands
LMB	Laboratory of Marine Biology, Free University, Brussels.
LOICZ	Land Ocean Interactions in the Coastal Zone
NHL	National Herbarium, Leiden
NIOZ	Netherlands Institute for Sea Research
NNM	National Museum of Natural History
ODP	Ocean Drilling Programme
OMZ	Oxygene Minimum Zone
SCOR	Scientific Committee on Oceanographic Research
SEM	Scanning Electron Microscope
SOZ	Netherlands Marine Research Foundation
TEMA	Training, Education and Mutual Assistance
VUB	Free University of Brussels, Belgium
WMO/VAP	World Meteorological Organisation, Voluntary Aid Programme

Colophon
Publication Netherlands Marine Research Foundation
Photography Fred Hoogervorst
Lay out Netherlands Marine Research Foundation
IOP Logo Henk Hobbelink
Printing Drukkerij Rosier